CULVERT DESIGN

4.3.1 Overview

A *culvert* is a short, closed (covered) conduit that conveys stormwater runoff under an embankment, usually a roadway. The primary purpose of a culvert is to convey surface water, but properly designed it may also be used to restrict flow and reduce downstream peak flows. In addition to the hydraulic function, a culvert must also support the embankment and/or roadway, and protect traffic and adjacent property owners from flood hazards to the extent practicable.

Most culvert design is empirical and relies on nomographs and "cookbook procedures." The purpose of the section is to provide an overview of culvert design criteria and procedures.

4.3.2 Symbols and Definitions

To provide consistency within this section as well as throughout this Manual the symbols listed in Table 4.3-1 will be used. These symbols were selected because of their wide use.

Table 4.3-1 Symbols and Definitions

Symbol	Definition	Units
A	Area of cross section of flow	ft^2
B	Barrel width	ft
C_d	Overtopping discharge coefficient	--
D	Culvert diameter or barrel depth	in or ft
d	Depth of flow	ft
d_c	Critical depth of flow	ft
d_u	Uniform depth of flow	ft
g	Acceleration of gravity	ft / s
H_f	Depth of pool or head, above the face section of invert	ft
h_o	Height of hydraulic grade line above outlet invert	ft
HW	Headwater depth above invert of culvert (depth from inlet invert to upstream total energy grade line)	ft
K_e	Inlet loss coefficient	--
L	Length of culvert	ft
N	Number of barrels	--
Q	Rate of discharge	cfs
S	Slope of culvert	ft / f
TW	Tailwater depth above invert of culvert	ft
V	Mean velocity of flow	ft / s
V_c	Critical velocity	ft / s

4.3.3 Design Criteria

The design of a culvert should take into account many different engineering and technical aspects at the culvert site and adjacent areas. The County recommends that culverts be designed by a Registered Profession Geo-Technical Engineer. The following design criteria should be considered for all culvert designs as applicable.

4.3.3.1 Frequency Flood

See Section 4.1 for design storm requirements for the sizing of culverts.

The 100-year frequency storm shall be routed through all culverts to be sure building structures (e.g., houses, commercial buildings) are not flooded or increased damage does not occur to the highway or adjacent property for this design event.

4.3.3.2 Velocity Limitations

Both minimum and maximum velocities should be considered when designing a culvert. The maximum velocity should be consistent with channel stability requirements at the culvert outlet. There is no specified maximum allowable velocity for reinforced concrete pipe, but outlet protection shall be provided where discharge velocities will cause erosion problems.

4.3.3.3 Buoyancy Protection

Headwalls, endwalls, slope paving or other means of anchoring to provide buoyancy protection should be considered for all flexible culverts.

4.3.3.4 Length and Slope

The culvert length and slope should be chosen to approximate existing topography and, to the degree practicable, the culvert invert should be aligned with the channel bottom and the skew angle of the stream, and the culvert entrance should match the geometry of the roadway embankment. The maximum slope using concrete pipe is 10% before pipe-restraining methods must be taken. Maximum drop in a drainage structure is 10 feet.

4.3.3.5 Debris Control

In designing debris control structures it is recommended that the Hydraulic Engineering Circular No. 9 entitled *Debris Control Structures* be consulted.

4.3.3.6 Headwater Limitations

Headwater is water above the culvert invert at the entrance end of the culvert. The allowable headwater elevation is that elevation above which damage may be caused to adjacent property and/or the roadway and is determined from an evaluation of land use upstream of the culvert and the proposed or existing roadway elevation. It is this allowable headwater depth that is the primary basis for sizing a culvert.

The following criteria related to headwater should be considered:

- The *allowable headwater* is the depth of water that can be ponded at the upstream end of the culvert during the design flood, which will be limited by one or more of the following constraints or conditions:
  (1) Headwater be nondamaging to upstream property
  (2) Ponding depth be no greater than the low point in the road grade (that is not at the culvert location)
  (3) Ponding depth be no greater than the elevation where flow diverts around the culvert
  (4) Elevations established to delineate floodplain zoning
  (5) 18-inch freeboard requirements
- The following HW/D criteria:
  (1) For drainage facilities with cross-sectional area equal to or less than 30 ft^2, HW/D should be equal to or less than 1.5

(2) For drainage facilities with cross-sectional area greater than 30 ft^2, HW/D should be equal to or less than 1.2

- The headwater should be checked for the 100-year flood to ensure compliance with flood plain management criteria and for most facilities the culvert should be sized to maintain flood-free conditions on major thoroughfares with 18-inch freeboard at the low-point of the road.
- The maximum acceptable outlet velocity should be identified (see subsection 4.4.3).
- Either the headwater should be set to produce acceptable velocities, or stabilization or energy dissipation should be provided where these velocities are exceeded.
- In general, the constraint that gives the lowest allowable headwater elevation establishes the criteria for the hydraulic calculations.
- Other site-specific design considerations should be addressed as required.

4.3.3.7 Tailwater Considerations

The hydraulic conditions downstream of the culvert site must be evaluated to determine a tailwater depth for a range of discharge. At times there may be a need for calculating backwater curves to establish the tailwater conditions. The following conditions must be considered:

- If the culvert outlet is operating with a free outfall, the critical depth and equivalent hydraulic grade line should be determined.
- For culverts that discharge to an open channel, the stage-discharge curve for the channel must be determined. See Section 4.4, Open Channel Design.
- If an upstream culvert outlet is located near a downstream culvert inlet, the headwater elevation of the downstream culvert may establish the design tailwater depth for the upstream culvert.
- If the culvert discharges to a lake, pond, or other major water body, the expected high water elevation of the particular water body may establish the culvert tailwater.

4.3.3.8 Storage

If storage is being assumed or will occur upstream of the culvert, refer to subsection 4.3.4.6 regarding storage routing as part of the culvert design.

4.3.3.9 Culvert Inlets

Hydraulic efficiency and cost can be significantly affected by inlet conditions. The inlet coefficient K_e is a measure of the hydraulic efficiency of the inlet, with lower values indicating greater efficiency. Recommended inlet coefficients are given in Table 4.3-2.

4.3.3.10 Inlets with Headwalls

Headwalls may be used for a variety of reasons, including increasing the efficiency of the inlet, providing embankment stability, providing embankment protection against erosion, providing protection from buoyancy, and shortening the length of the required structure. Headwalls are required for all culverts and where buoyancy protection is necessary. If high headwater depths are to be encountered, or the approach velocity in the channel will cause scour, a short channel apron should be provided at the toe of the headwall.

This apron should extend at least one pipe diameter upstream from the entrance, and the top of the apron should not protrude above the normal streambed elevation.

Table 4.3-2 Inlet Coefficients

Type of Structure and Design of Entrance	Coefficient K_e
Pipe, Concrete	
Projecting from fill, socket end (grove-end)	0.2
Projecting from fill, square cut end	0.5
Headwall or headwall and wingwalls	0.2
Socket end of pipe (groove-end)	0.2
Square-edge	0.5
Rounded [radius = 1/12 (D)]	0.2
Mitered to conform to fill slope	0.7
* End-Section conforming to fill slope	0.5
Beveled edges, 33.7° or 45° bevels	0.2
Side- or slope-tapered inlet	0.2
Pipe, or Pipe-Arch, Corrugated Metal[1]	
Projecting from fill (no headwall)	
Headwall or headwall and wingwalls square-edge	0.5
Mitered to fill slope, paved or unpaved slope	0.7
* End-Section conforming to fill slope	0.5
Beveled edges, 33.7° or 45° bevels	0.2
Side- or slope-tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of [1/12 (D)] or beveled edges on 3	0.2
Wingwalls at 30° to 75° to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of [1/12 (D)] or beveled top edge	0.2
Wingwalls at 10° to 25° to barrel	
Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side- or slope-tapered inlet	0.2

[1] Although laboratory tests have not been completed on K_e values for High-Density Polyethylene (HDPE) pipes, the K_e values for corrugated metal pipes are recommended for HDPE pipes.

* Note: End Section conforming to fill slope, made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests, they are equivalent in operation to a headwall in both inlet and outlet control.

Source: HDS No. 5, 1985

4.3.3.11 Wingwalls and Aprons

Wingwalls are used where the side slopes of the channel adjacent to the entrance are unstable or where the culvert is skewed to the normal channel flow.

4.3.3.12 Improved Inlets

Where inlet conditions control the amount of flow that can pass through the culvert, improved inlets can greatly increase the hydraulic performance of the culvert.

4.3.3.13 Material Selection

Culverts shall be constructed of Class III reinforced concrete pipe, Class IV reinforced concrete pipe, as appropriate or concrete box culverts. Design of said facilities shall be in accordance with GA DOT standards specification and construction standards.

4.3.3.14 Culvert Skews

Culvert skews shall not exceed 45 degrees as measured from a line perpendicular to the roadway centerline without approval.

4.3.3.15 Culvert Sizes

The minimum allowable pipe diameter shall be 18 inches. Do not discharge the contents of a larger pipe into a smaller one even though the capacity of the smaller pipe may be greater due to a steeper slope. At the discretion of Columbia County, the design of all portions of a drainage system which is expected to carry between 50 and 150 cfs for the 100-year storm event shall be based on the 100-year plus three foot elevation if one of the following conditions exists:

1. The estimated runoff would create a hazard for all adjacent property or residents; or
2. The flood limits would be of such magnitude that adjacent residents should be informed of these limits.

For all portions of the drainage system which are expected to carry 150 cfs or more for the 100-year storm event, the 100-year plus three feet flood elevation shall be computed and shown within the Stormwater Management Plan.

4.3.3.16 Weep Holes

Weep holes are sometimes used to relieve uplift pressure. Filter materials should be used in conjunction with the weep holes in order to intercept the flow and prevent the formation of piping channels. The filter materials should be designed as an underdrain filter so as not to become clogged and so that piping can not occur through the pervious material and the weep hole.

Table 4.3-3 Manning's n values

Type of Conduit	Wall & Joint Description	Manning's n
Concrete Pipe	Good joints, smooth walls	0.012
	Good joints, rough walls	0.016
	Poor joints, rough walls	0.017
Concrete Box	Good joints, smooth finished walls	0.012
	Poor joints, rough, unfinished walls	0.018
Corrugated Metal Pipes and Boxes Annular Corrugations	2 2/3-inch by 1/2-inch corrugations	0.024
	6-inch by 1-inch corrugations	0.025
	5-inch by 1inch corrugations	0.026
	3-inch by 1-inch corrugations	0.028
	6-inch by 2-inch structural plate	0.035
	9-inch by 2 1/2-inch structural plate	0.035
Corrugated Metal Pipes, Helical Corrugations, Full Circular Flow	2 2/3-inch by 1/2-inch corrugated 24-inch plate width	0.012
Spiral Rib Metal Pipe	3/4 by 3/4 in recesses at 12-inch spacing, good joints	0.013
High Density Polyethylene (HDPE)	Corrugated Smooth Line	0.015
	Corrugated	0.02
Polyvinyl Chloride (PVC)		0.011

Source: HDS No. 5, 1985

Note: For further information concerning Manning n values for selected conduits, consult Hydraulic design of Highway Culverts, Federal Highway Administration, HDS No. 5, page 163

4.3.3.17 Outlet Protection

See Section 4.5 for information on the design of outlet protection. Outlet protection should be provided for the 25-year storm. For erosive velocity in addition to rip-rap other energy dissipation control measures will be required.

4.3.3.18 Erosion and Sediment Control

Erosion and sediment control shall be in accordance with the latest approved Columbia County Soil Erosion and Sediment Control Ordinance. See also the Manual for Erosion and Sediment Control in Georgia for design standards and details related to erosion and sediment control.

4.3.3.19 Environmental Considerations

Where compatible with good hydraulic engineering, a site should be selected that will permit the culvert to be constructed to cause the least impact on the stream or wetlands. This selection must consider the entire site, including any necessary lead channels.

4.3.4 Design Procedures

4.3.4.1 Types of Flow Control

There are two types of flow conditions for culverts that are based upon the location of the control section and the critical flow depth:

Inlet Control – Inlet control occurs when the culvert barrel is capable of conveying more flow that the inlet will accept. This typically happens when a culvert is operating on a steep slope. The control section of a culvert is located just inside the entrance. Critical depth occurs at or near this location, and the flow regime immediately downstream is supercritical.

Outlet Control – Outlet control flow occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept. The control section for outlet control flow in a culvert is located at the barrel exit or further downstream. Either subcritical or pressure flow exists in the culvert barrel under these conditions.

Proper culvert design and analysis requires checking for both inlet and outlet control to determine which will govern particular culvert designs. For more information on inlet and outlet control, see the FHWA Hydraulic Design of Highway Culverts, HDS-5, 1985.

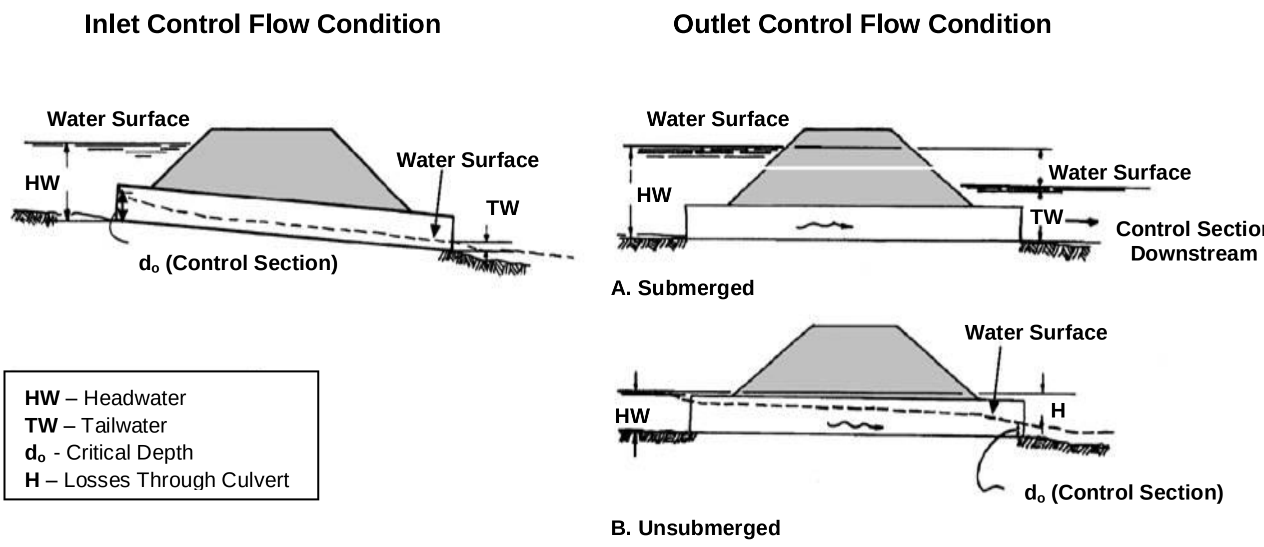


Figure 4.3-1 Culvert Flow Conditions
(Adapted from: HDS-5, 1985)

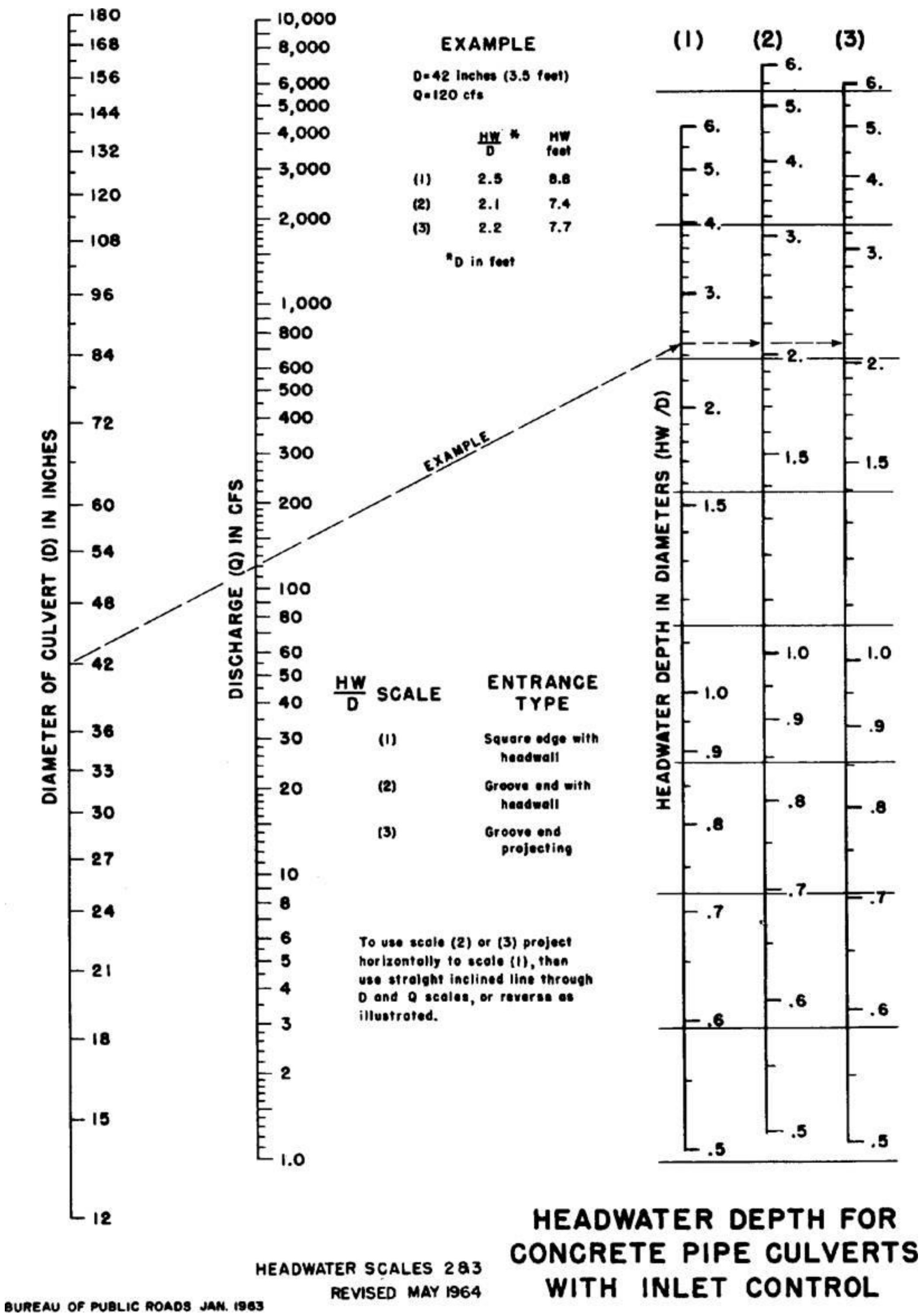


Figure 4.3-2(a) Headwater Depth for Concrete Pipe Culvert with Inlet Control

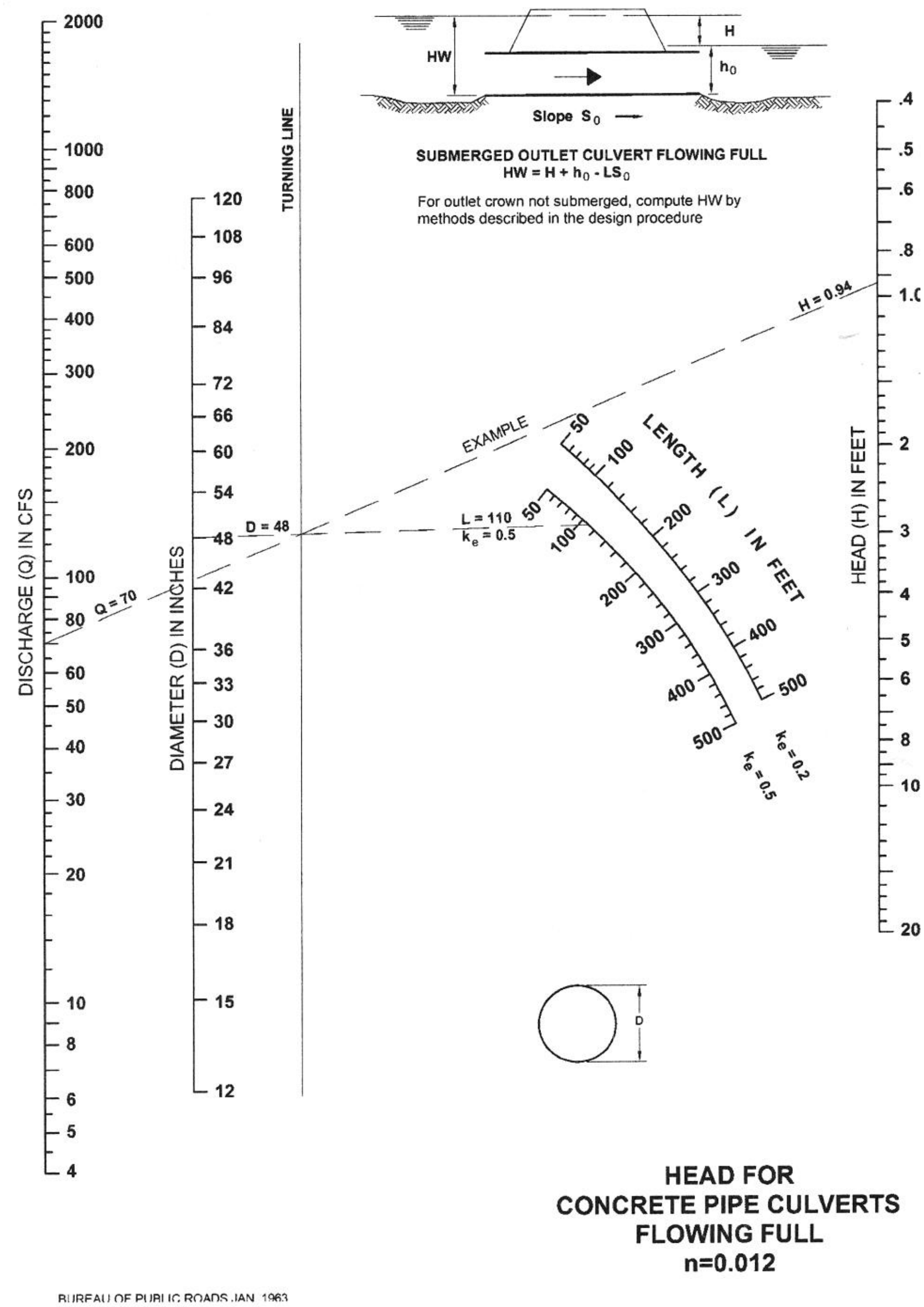


Figure 4.3-2(b) Head for Concrete Pipe Culverts Flowing Full

4.3.4.2 Procedures

There are two procedures for designing culverts: manual use of inlet and outlet control nomographs, and the use computer programs such as HY8. It is recommended that the HY8 computer model or equivalent be used for culvert design. The computer software package HYDRAIN, which includes HY8, uses the theoretical basis from the nomographs to size culverts.

In addition, this software can evaluate improved inlets, route hydrographs, consider road overtopping, and evaluate outlet streambed scour. By using water surface profiles, this procedure is more accurate in predicting backwater effects and outlet scour.

4.3.4.3 Nomographs

The use of culvert design nomographs requires a trial and error solution. Nomograph solutions provide reliable designs for many applications. It should be remembered that velocity, hydrograph routing, roadway overtopping, and outlet scour require additional, separate computations beyond what can be obtained from the nomographs. Figures 4.3-2(a) and (b) show examples of an inlet control and outlet control nomograph for the design of concrete pipe culverts. For other culvert designs, refer to the complete set of nomographs in subsection 4.3.8.

4.3.4.4 Design Procedure

The following design procedure requires the use of inlet and outlet nomographs.

Step 1: List design data:

Q	=	discharge (cfs)	L	=	culvert length (ft)
S	=	culvert slope (ft/ft)	TW	=	tailwater depth (ft)
V	=	velocity for trial diameter (ft/s)	K_e	=	inlet loss coefficient
HW	=	allowable headwater depth for the design storm (ft)			

Step 2: Determine trail culvert size by assuming a trial velocity 3 to 5 ft/s and computing the culvert area, A = Q/V. Determine the culvert diameter (inches).

Step 3: Find the actual HW for the trial size culvert for both inlet and outlet control.

- For inlet control, enter inlet control nomograph with D and Q and find HW/D for the proper entrance type.
- Compute HW and, if too large or too small, try another culvert size before computing HW for outlet control.
- For outlet control enter the outlet control nomograph with the culvert length, entrance loss coefficient, and trial culvert diameter.
- To compute HW, connect the length scale for the type of entrance condition and culvert diameter scale with a straight line, pivot on the turning line, and draw a straight line from the design discharge through the turning point to the head loss scale H. Compute the headwater elevation HW from the equation:

$$\mathbf{HW = H + h_o - LS} \qquad \textbf{(4.3.1)}$$

Where: h_o = ½ (critical depth + D), or tailwater depth, whichever is greater
L = culvert length
S = culvert slope

Step 4: Compare the computed headwaters and use the higher HW nomograph to determine if the culvert is under inlet or outlet control.

- If inlet control governs, then the design is complete and no further analysis is required.

- If <u>outlet control</u> governs and the HW is unacceptable, select a larger trial size and find another HW with the outlet control nomographs. Since the smaller size of culvert had been selected for allowable HW by the inlet control nomographs, the inlet control for the larger pipe need not be checked.

Step 5: Calculate exit velocity and if erosion problems might be expected, refer to Section 4.5 for appropriate energy dissipation designs.

4.3.4.5 Performance Curves - Roadway Overtopping

A performance curve for any culvert can be obtained from the nomographs by repeating the steps outlined above for a range of discharges that are of interest for that particular culvert design. A graph is then plotted of headwater versus discharge with sufficient points so that a curve can be drawn through the range of interest. These curves are applicable through a range of headwater, velocities, and scour depths versus discharges for a length and type of culvert. Usually charts with length intervals of 25 to 50 feet are satisfactory for design purposes. Such computations are made much easier by the use of computer programs.

To complete the culvert design, roadway overtopping should be analyzed. A performance curve showing the culvert flow as well as the flow across the roadway is a useful analysis tool. Rather than using a trial and error procedure to determine the flow division between the overtopping flow and the culvert flow, an overall performance curve can be developed.

The overall performance curve can be determined as follows:

Step 1: Select a range of flow rates and determine the corresponding headwater elevations for the culvert flow alone. The flow rates should fall above and below the design discharge and cover the entire flow range of interest. Both inlet and outlet control headwaters should be calculated.

Step 2: Combine the inlet and outlet control performance curves to define a single performance curve for the culvert.

Step 3: When the culvert headwater elevations exceed the roadway crest elevation, overtopping will begin. Calculate the equivalent upstream water surface depth above the roadway (crest of weir) for each selected flow rate. Use these water surface depths and equation 4.3.2 to calculate flow rates across the roadway.

$$\mathbf{Q = C_d L\ (HW)^{1.5}} \qquad \mathbf{(4.3.2)}$$

Where: Q = overtopping flow rate (ft3/s)

C_d = overtopping discharge coefficient

L = length of roadway (ft)

HW = upstream depth, measured from the roadway crest to the water surface upstream of the weir drawdown (ft)

Note: See Figure 4.3-3 on the next page for guidance in determining a value for C_d. For more information on calculating overtopping flow rates see pages 39 – 42 in HDS No. 5.

Step 4: Add the culvert flow and the roadway overtopping flow at the corresponding headwater elevations to obtain the overall culvert performance curve.

4.3.4.6 Storage Routing

A significant storage capacity behind a highway embankment attenuates a flood hydrograph. Because of the reduction of the peak discharge associated with this attenuation, the required capacity of the culvert, and its size, may be reduced considerably. If significant storage is anticipated behind a culvert, the design should be checked by routing the design hydrographs through the culvert to determine the discharge and stage behind the culvert. See subsection 4.3.7 and Section 2.2 for more information on routing. Additional routing procedures are outlined in Hydraulic Design of Highway Culverts, Section V - Storage Routing, HDS No. 5, Federal Highway Administration.

Note: Storage should be taken into consideration only if the storage area will remain available for the life of the culvert as a result of purchase of ownership or right-of-way or an easement has been acquired.

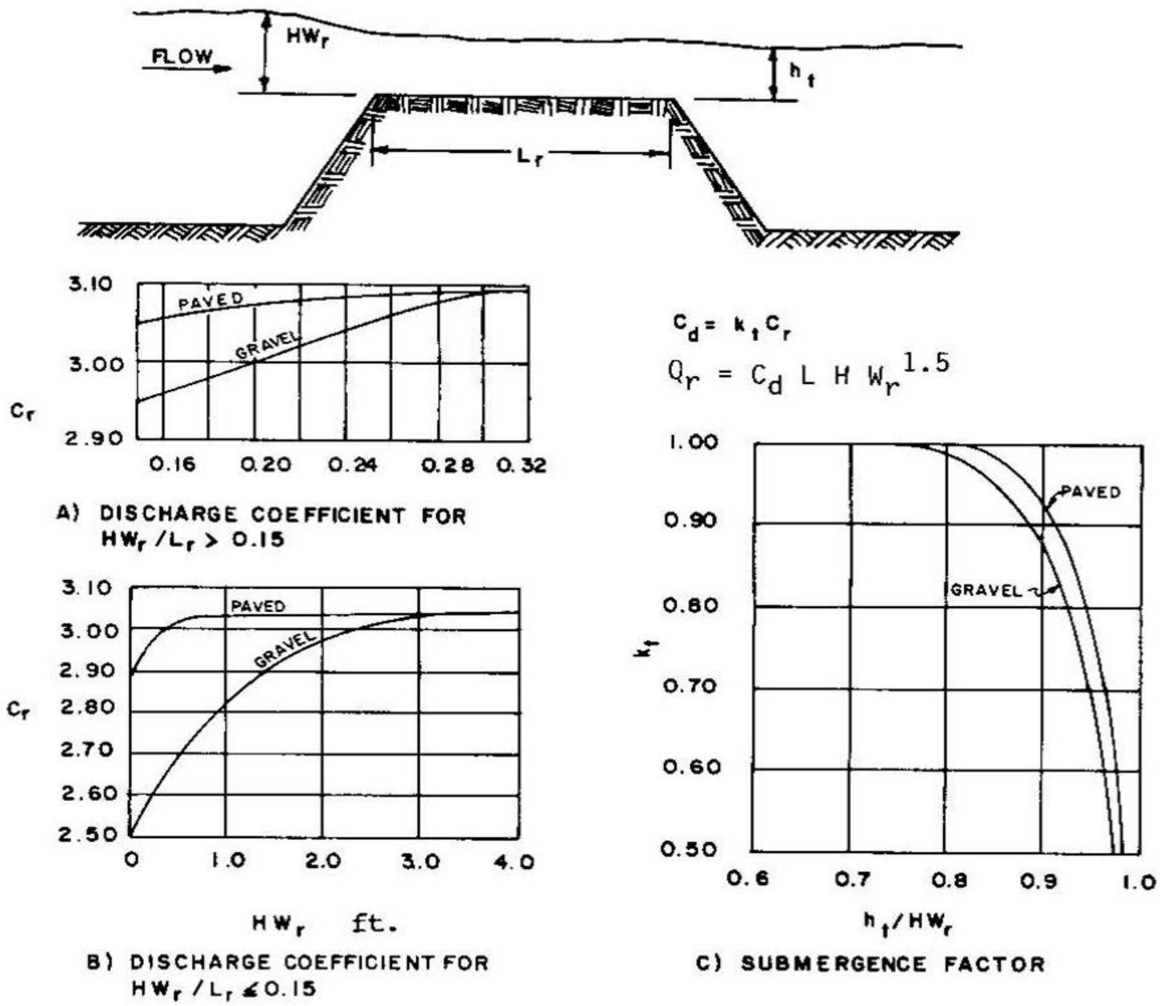


Figure 4.3-3 Discharge Coefficients for Roadway Overtopping

(Source: HDS No. 5, 1985)

4.3.5 Culvert Design Example

4.3.5.1 Introduction

The following example problem illustrates the procedures to be used in designing culverts using the nomographs.

4.3.5.2 Example

Size a culvert given the following example data, which were determined by physical limitations at the culvert site and hydraulic procedures described elsewhere in this handbook.

4.3.5.3 Example Data

Input Data

Discharge for 2-yr flood = 35 cfs
Discharge for 25-yr flood = 70 cfs
Allowable HW for 25-yr discharge = 5.25 ft

Length of culvert = 100 ft
Natural channel invert elevations - inlet = 15.50 ft, outlet = 14.30 ft
Culvert slope = 0.012 ft/ft
Tailwater depth for 25-yr discharge = 3.5 ft
Tailwater depth is the normal depth in downstream channel
Entrance type = Groove end with headwall

4.3.5.4 Computations

(1) Assume a culvert velocity of 5 ft/s. Required flow area = $\mathbf{70\ cfs / 5\ ft/s = 14\ ft^2}$ (for the 25-yr recurrence flood).

(2) The corresponding culvert diameter is about 48 in. This can be calculated by using the formula for area of a circle: $\mathbf{Area = (3.14D^2)/4 \text{ or } D = (Area\ \ times\, 4/3.14)^{0.5}}$

Therefore: $\mathbf{D = ((14\ sq\ ft * 4)/3.14)^{0.5} * 12\ in/ft) = 50.7\ in}$

(3) A grooved end culvert with a headwall is selected for the design. Using the inlet control nomograph (Figure 4.3-1), with a pipe diameter of 48 inches and a discharge of 70 cfs; read a HW/D value of 0.93.

(4) The depth of headwater (HW) is $\mathbf{(0.93)*(4) = 3.72\ ft}$, which is less than the allowable headwater of 5.25 ft. Since 3.72 ft is considerably less than 5.25 try a small culvert.

(5) Using the same procedures outlined in steps 4 and 5 the following results were obtained.

42-inch culvert – HW = 4.13 ft
36-inch culvert – HW = 4.98 ft

Select a 36-inch culvert to check for outlet control.

(6) The culvert is checked for outlet control by using Figure 4.3-2.

With an entrance loss coefficient K_e of 0.20, a culvert length of 100 ft, and a pipe diameter of 36 in., an H value of 2.8 ft is determined. The headwater for outlet control is computed by the equation: $\mathbf{HW = h_o - LS}$

Compute h_o
$\mathbf{h_o = T_w \text{ or } \%}$ (critical depth in culvert + D), whichever is greater.
$\mathbf{h_o = 3.5\ ft\ pr\ h_o = 1/2\,(2.7 + 3.0) = 2.85\ ft}$

Note: critical depth is obtained from Chart 4 on page 4.3-20

Therefore: $\mathbf{h_o = 3.5\ ft}$

The headwater depth for outlet control is:

$$\mathbf{HW = H + h_o - LS = 2.8 + 3.5 - (100) * (0.012) = 5.10\ ft}$$

(7) Since HW for inlet outlet (5.10 ft) is greater than the HW for inlet control (4.98 ft), outlet control governs the culvert design. Thus, the maximum headwater expected for a 25-year recurrence flood is 5.10 ft, which is less than the allowable headwater of 5.25 ft.

(8) Estimate outlet exit velocity. Since this culvert is on outlet control and discharges into an open channel downstream with tailwater above culvert, the culvert will be flowing full at the flow depth in the channel. Using the design peak discharge of 70 cfs and the area of a 36-inch or 3.0-foot diameter culvert the exit velocity will be:

$$\mathbf{Q = VA}$$

Therefore: $\mathbf{V = 706 / (3.14(3.0)^2) / 4 = 9.9\ ft / s}$

With this high velocity, consideration should be given to provide an energy dissipater at the culvert outlet. See Section 4.5 (*Energy Dissipation Design)*.

(9) Check for minimum velocity using the 2-year flow of 35 cfs. Therefore:

$\mathbf{V = 35 / (3.14(3.0)^2) / 4 = 5.0\ ft / s}$ > minimum of 2.5 - OK

(10) The 100-year flow should be routed through the culvert to determine if any flooding problems will be associated with this flood.

Figure 4.3-4 provides a convenient form to organize culvert design calculations.

PROJECT: ____________

STATION: ____________

SHEET ______ OF ______

CULVERT DESIGN FORM

DESIGNER / DATE: ______ OF ______

REVIEWER / DATE: ______ OF ______

HYDROLOGICAL DATA

SEE ADD'L SHTS.

☐ METHOD: ____________

☐ DRAINAGE AREA: ______ ☐ STREAM SLOPE: ______

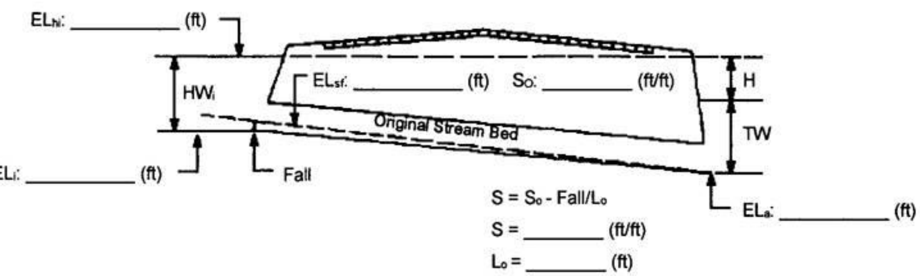
☐ CHANNEL SHAPE: ____________

☐ ROUTING: ______ ☐ OTHER: ______

DESIGN FLOWS/TAILWATER

R.I. (YEARS)	FLOW (cfs)	TW (ft)

ROADWAY ELEVATION: ____________ (ft)



$S = S_o - Fall/L_o$

$S =$ ______ (ft/ft)

$L_o =$ ______ (ft)

CULVERT DESCRIPTION: MATERIAL-SHAPE-SIZE-ENTRANCE	TOTAL FLOW Q (cfs)	FLOW PER BARREL Q/N (1)	HEADWATER CALCULATIONS: INLET CONTROL HW/D (2)	HW_i	FALL (3)	EL_{hi} (4)	OUTLET CONTROL TW (5)	d_c	$\frac{d_c + D}{2}$	h_o (6)	k_e	H (7)	EL_{ho} (8)	CONTROL HEADWATER ELEVATION	OUTLET VELOCITY	COMMENTS

TECHNICAL FOOTNOTES:

(1) USE Q/NB FOR BOX CULVERTS

(2) $HW_i/D = HW/D$ OR HW_i/D FROM DESIGN CHARTS

(3) FALL = $HW_i - (EL_{hd} - EL_{sf})$; FALL IS ZERO FOR CULVERTS ON GRADE

(4) $EL_{hi} = HW_i + EL_i$ (INVERT OF INLET CONTROL SECTION)

(5) TW BASED ON DOWN STREAM CONTROL OR FLOW DEPTH IN CHANNEL

(6) $h_o = TW$ or $(d_c + D)/2$ (WHICHEVER IS GREATER)

(7) $H = [1+k_e+(29 n^2L)/R^{1.33}] V^2/2g$

(8) $EL_{ho} = EL_o + H + h_o$

SUSCRIPT DEFINITIONS:

a. Approximate
f. Culvert Face
hd. Design Headwater
hi. Headwater in Inlet Control
ho. Headwater in Outlet Control
i. Inlet Control Section
o. Outlet
sf. Streamed at Culvert Face
tw. Tailwater

COMMENTS / DISCUSSION:

CULVERT BARREL SELECTED:

SIZE: ____________

SHAPE: ____________

MATERIAL: ____________ n ______

ENTRANCE: ____________

Figure 4.3-4 Culvert Design Calculation Form
(Source: HDS No. 5, 1985)

4.3.6 Design Procedures for Beveled-Edged Inlets

4.3.6.1 Introduction

Improved inlets include inlet geometry refinements beyond those normally used in conventional culvert design practice. Several degrees of improvements are possible, including bevel-edged, side-tapered, and slope-tapered inlets. Those designers interested in using side- and slope-- tapered inlets should consult the detailed design criteria and example designs outlined in the U. S. Department of Transportation publication Hydraulic Engineering Circular No. 5 entitled, Hydraulic Design of Highway Culverts.

4.3.6.2 Design Figures

Four inlet control figures for culverts with beveled edges are included in subsection 4.3.8.

Chart	Page	Use for:
3	4.3-19	circular pipe culverts with beveled rings
10	4.3-26	90o headwalls (same for 90 ^{o} wingwalls)
11	4.3-27	skewed headwalls
12	4.3-28	wingwalls with flare angles of 18 to 45 degrees

The following symbols are used in these figures:

B - Width of culvert barrel or diameter of pipe culvert

D - Height of box culvert or diameter of pipe culvert

H_f - Depth of pool or head, above the face section of invert

N - Number of barrels

Q - Design discharge

4.3.6.3 Design Procedure

The figures for bevel-edged inlets are used for design in the same manner as the conventional inlet design nomographs discussed earlier. Note that Charts 10, 11, and 12 in subsection 4.3.8 apply only to bevels having either a 33 ^{o} angle (1.5:1) or a 45 ^{o} angle (1:1).

For box culverts the dimensions of the bevels to be used are based on the culvert dimensions. The top bevel dimension is determined by multiplying the height of the culvert by a factor. The side bevel dimensions are determined by multiplying the width of the culvert by a factor. For a 1:1 bevel, the factor is 0.5 inch/ft. For a 1.5:1 bevel the factor is 1 inch/ft. For example, the minimum bevel dimensions for an 8 ft x 6 ft box culvert with 1:1 bevels would be:

Top Bevel = **d = 6 ft x 0.5 inch/ft = 3 inches**

Side Bevel = **b = 8 ft x 0.5 inch/ft = 4 inches**

For a 1.5:1 bevel computations would result in d = 6 and b = 8 inches.

4.3.6.4 Design Figure Limits

The improved inlet design figures are based on research results from culvert models with barrel width, B, to depth, D, ratios of from 0.5:1 to 2:1. For box culverts with more than one barrel, the figures are used in the same manner as for a single barrel, except that the bevels must be sized on the basis of the total clear opening rather than on individual barrel size.

For example, in a double 8 ft by 8 ft box culvert:

Top Bevel is proportioned based on the height of 8 feet which results in a bevel of 4 in. for the 1:1 bevel and 8 in. for the 1.5:1 bevel.

Side Bevel is proportioned based on the clear width of 16 feet, which results in a bevel of 8 in. for the 1:1 bevel and 16 in. for the 1.5:1 bevel.

4.3.6.5 Multibarrel Installations

For multibarrel installations exceeding a 3:1 width to depth ratio, the side bevels become excessively large when proportioned on the basis of the total clear width. For these structures, it is recommended that the side bevel be sized in proportion to the total clear width, B, or three times the height, whichever is smaller.

The top bevel dimension should always be based on the culvert height.

The shape of the upstream edge of the intermediate walls of multibarrel installations is not as important to the hydraulic performance of a culvert as the edge condition of the top and sides. Therefore, the edges of these walls may be square, rounded with a radius of one-half their thickness, chamfered, or beveled. The intermediate walls may also project from the face and slope downward to the channel bottom to help direct debris through the culvert.

Multibarrel pipe culverts should be designed as a series of single barrel installations since each pipe requires a separate bevel.

4.3.6.6 Skewed Inlets

It is recommended that Chart 11 for skewed inlets not be used for multiple barrel installations, as the intermediate wall could cause an extreme contraction in the downstream barrels. This would result in underdesign due to a greatly reduced capacity. Skewed inlets (at an angle with the centerline of the stream) should be avoided whenever possible and should not be used with side- or slope-tapered inlets. It is important to align culverts with streams in order to avoid erosion problems associated with changing the direction of the natural stream flow.

4.3.7 Flood Routing and Culvert Design

4.3.7.1 Introduction

Flood routing through a culvert is a practice that evaluates the effect of temporary upstream ponding caused by the culvert's backwater. By not considering flood routing it is possible that the findings from culvert analyses will be conservative. If the selected allowable headwater is accepted without flood routing, then costly overdesign of both the culvert and outlet protection may result, depending on the amount of temporary storage involved. However, if storage is used in the design of culverts, consideration should be given to:

- The total area of flooding,
- The average time that bankfull stage is exceeded for the design flood up to 48 hours in rural areas or 6 hours in urban areas, and
- Ensuring that the storage area will remain available for the life of the culvert through the purchase of right-of-way or easement.

4.3.7.2 Design Procedure

The design procedure for flood routing through a culvert is the same as for reservoir routing. The site data and roadway geometry are obtained and the hydrology analysis completed to include estimating a hydrograph. Once this essential information is available, the culvert can be designed. Flood routing through a culvert can be time consuming. It is recommended that a computer program be used to perform routing calculations; however, an engineer should be familiar with the culvert flood routing design process.

A multiple trial and error procedure is required for culvert flood routing. In general:

Step 1: A trial culvert(s) is selected

Step 2: A trial discharge for a particular hydrograph time increment (selected time increment to estimate discharge from the design hydrograph) is selected

Step 3: Flood routing computations are made with successive trial discharges until the flood routing equation is satisfied

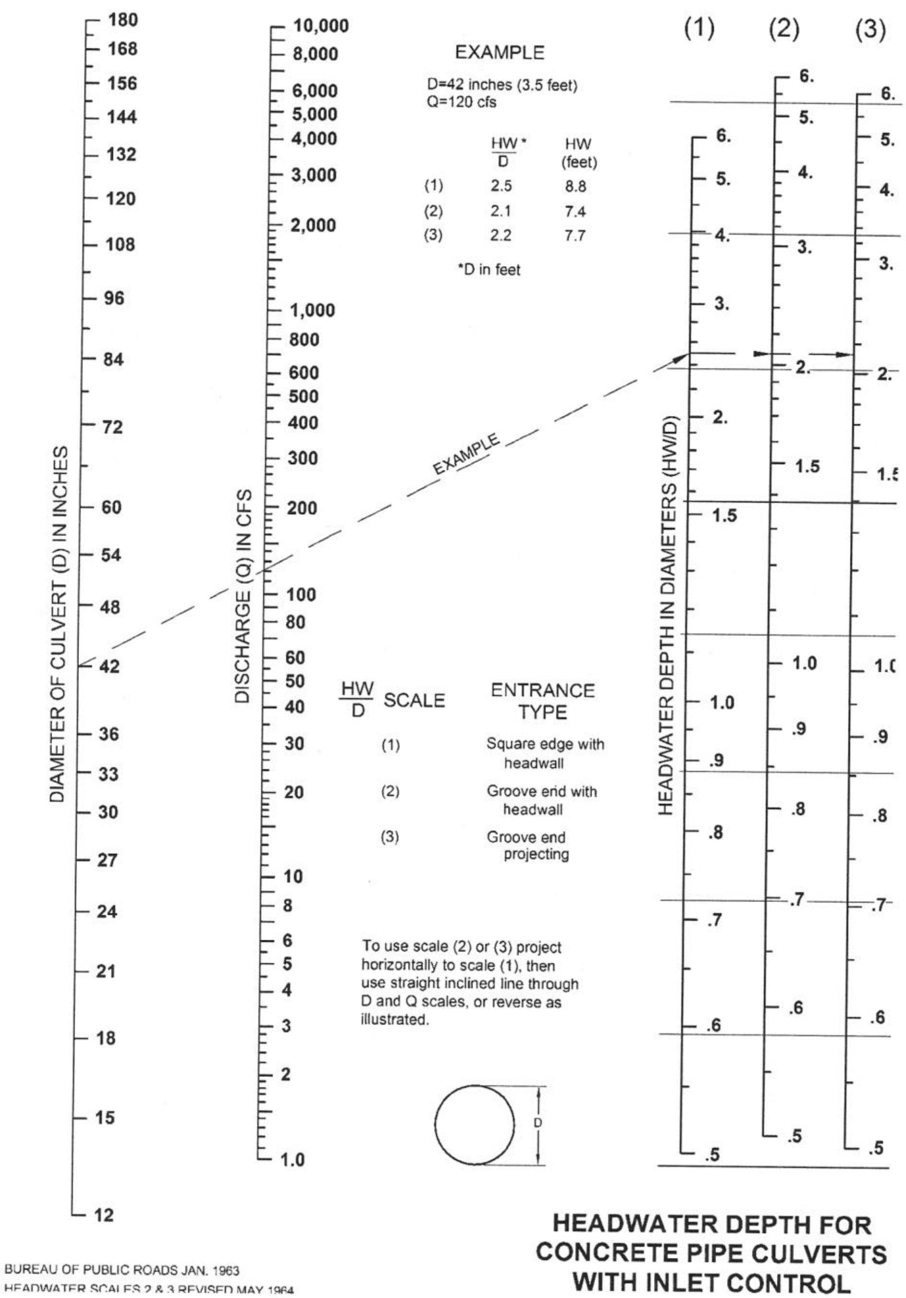
Step 4: The hydraulic findings are compared to the selected site criteria

Step 5: If the selected site criteria are satisfied, then a trial discharge for the next time increment is selected and this procedure is repeated; if not, a new trial culvert is selected and the entire procedure is repeated.

4.3.8 Culvert Design Charts and Nomographs

<u>All of the figures in this section are from the AASHTO Model Drainage Manual, 1991.</u>

CHART 1



HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

CHART 2

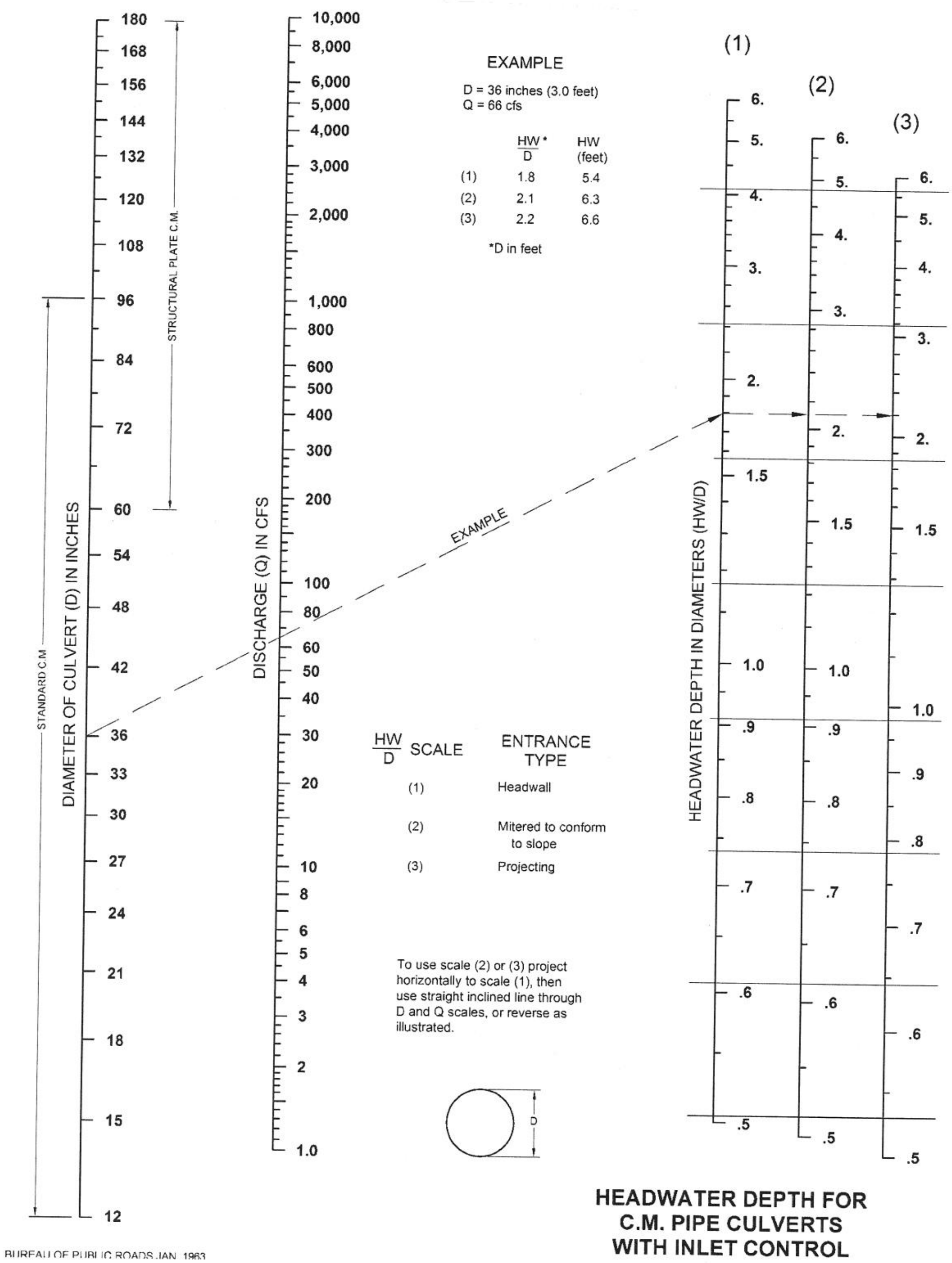
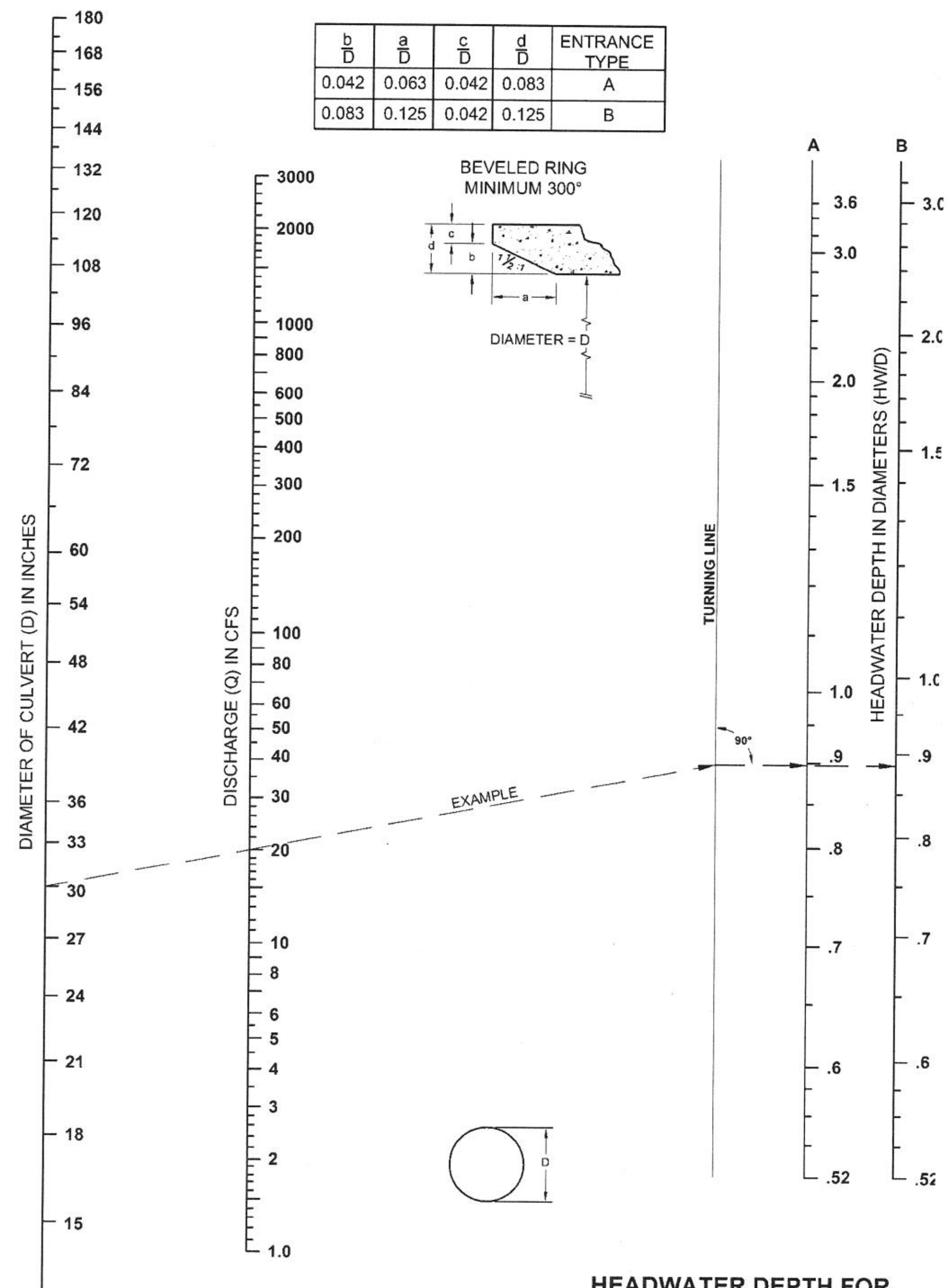

EXAMPLE
D = 36 inches (3.0 feet)
Q = 66 cfs
HW*/D HW (feet)
(1) 1.8 5.4
(2) 2.1 6.3
(3) 2.2 6.6
*D in feet
DIAMETER OF CULVERT (D) IN INCHES
STANDARD C.M.
STRUCTURAL PLATE C.M.
DISCHARGE (Q) IN CFS
HEADWATER DEPTH IN DIAMETERS (HW/D)
EXAMPLE
HW/D SCALE ENTRANCE TYPE
(1) Headwall
(2) Mitered to conform to slope
(3) Projecting
To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.
D
BUREAU OF PUBLIC ROADS JAN. 1963
HEADWATER DEPTH FOR C.M. PIPE CULVERTS WITH INLET CONTROL

CHART 3

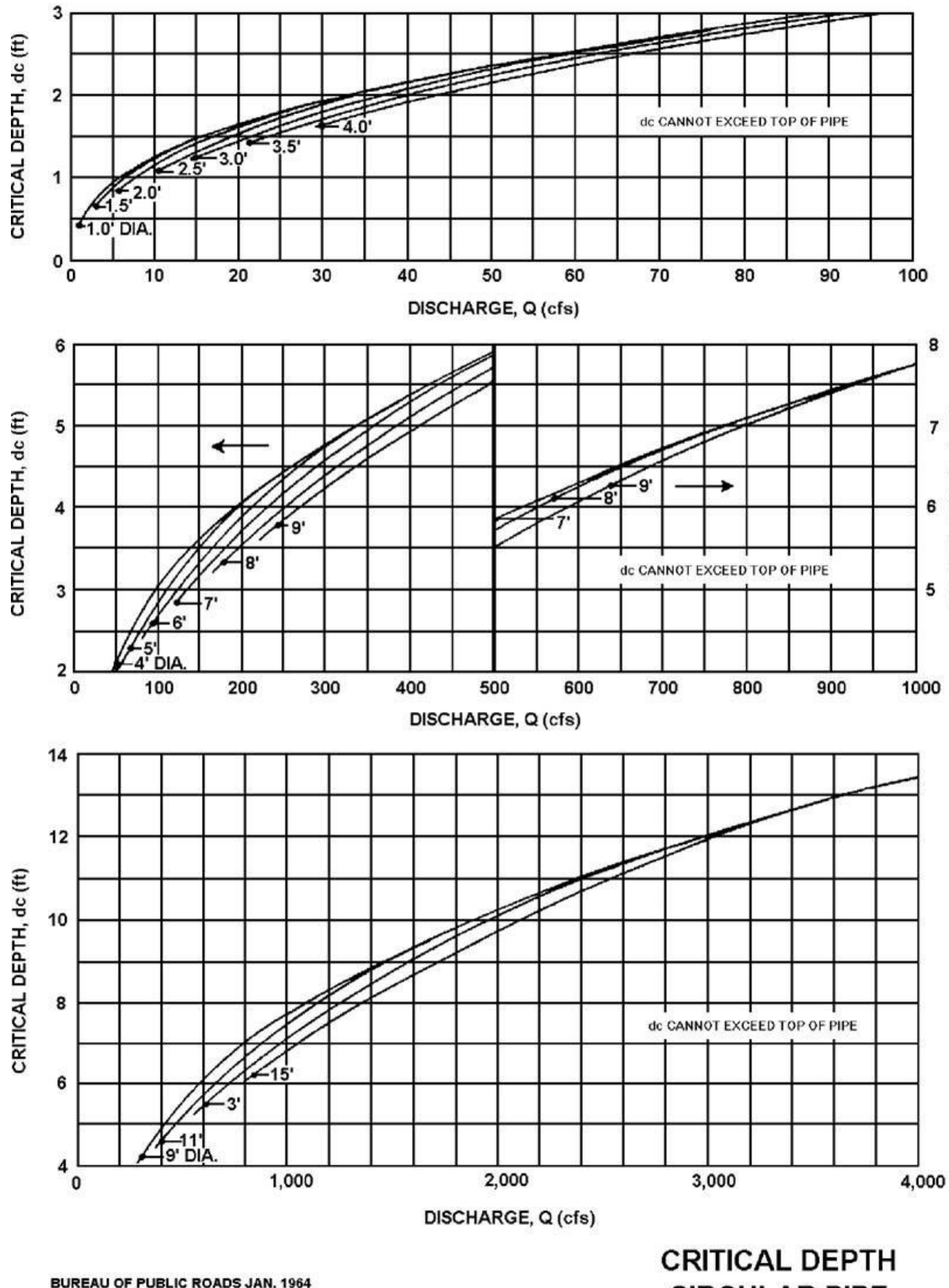


b/D	a/D	c/D	d/D	ENTRANCE TYPE
0.042	0.063	0.042	0.083	A
0.083	0.125	0.042	0.125	B

HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH BEVELED RING INLET CONTROL

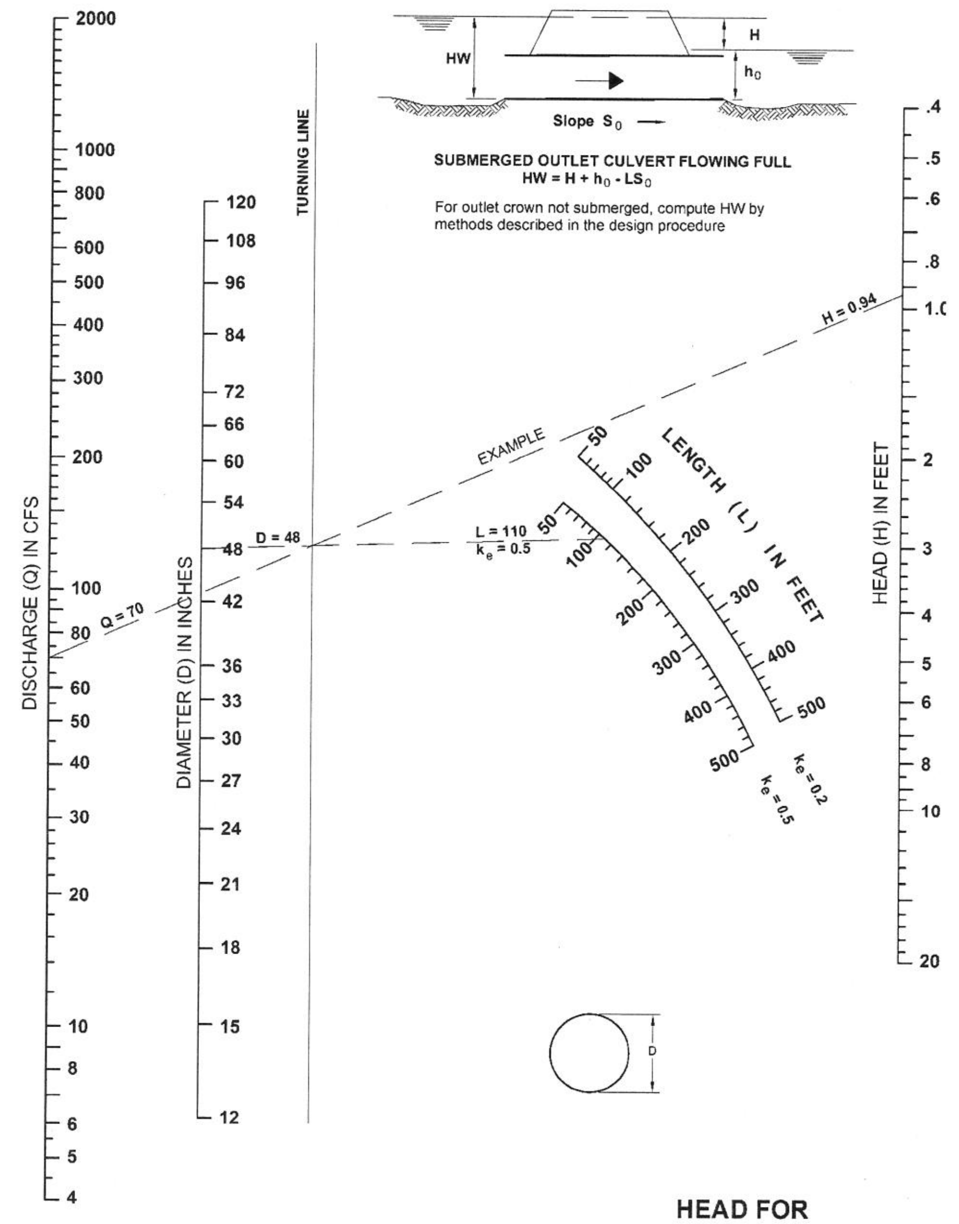
FEDERAL HIGHWAY ADMINISTRATION
MAY 1973

CHART 4



CRITICAL DEPTH
CIRCULAR PIPE

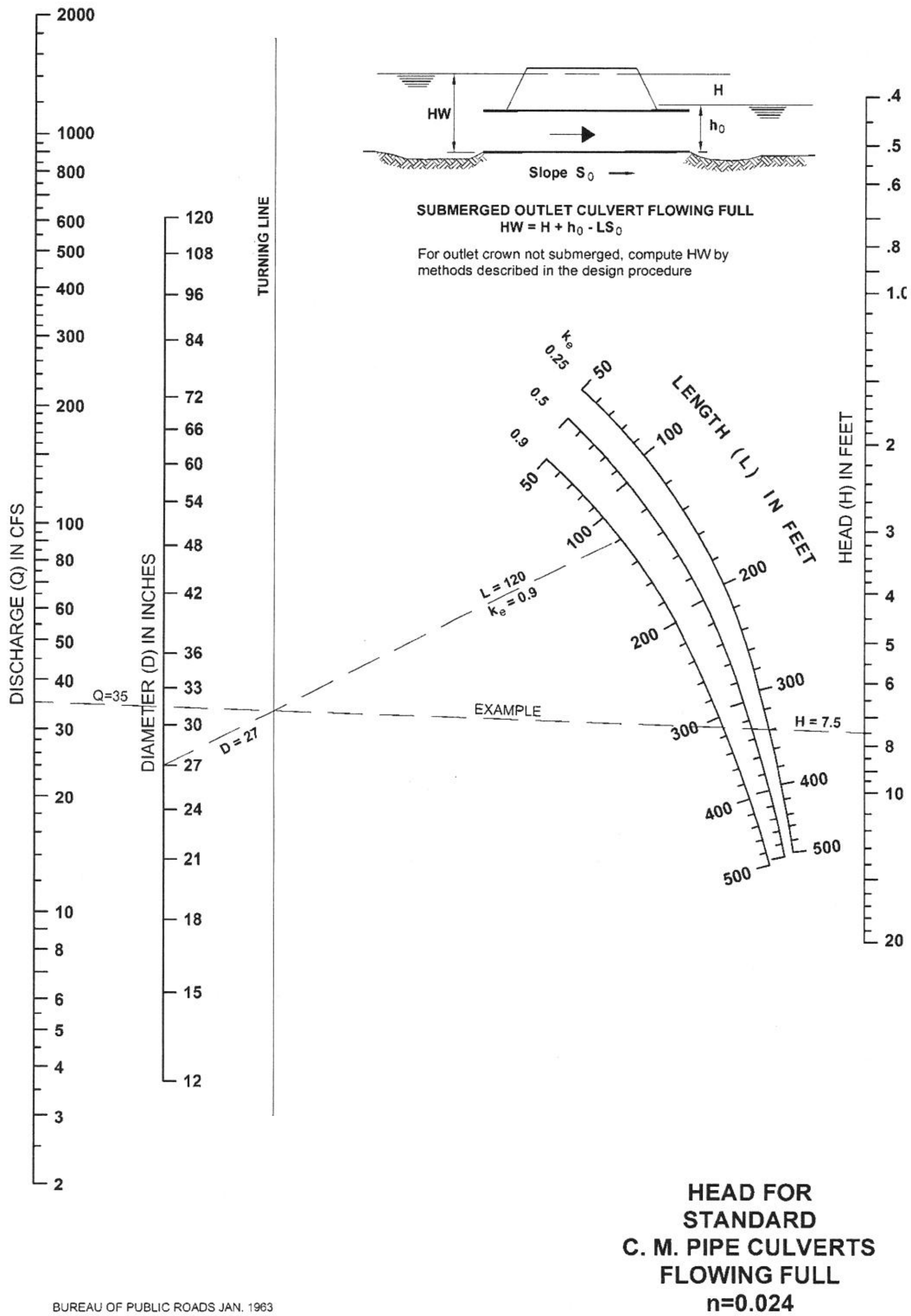
CHART 5



HEAD FOR CONCRETE PIPE CULVERTS FLOWING FULL n=0.012

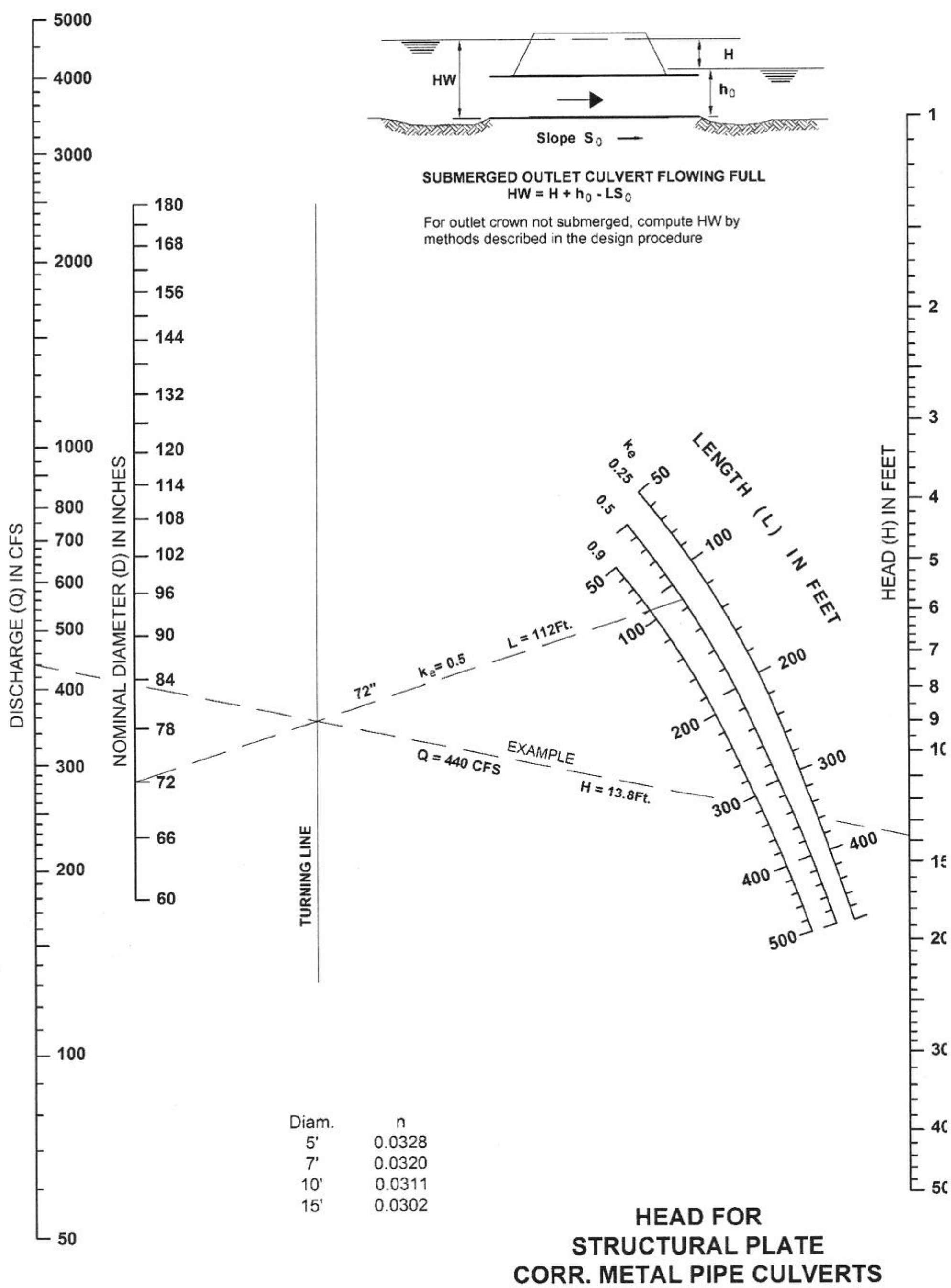
BUREAU OF PUBLIC ROADS JAN. 1963

CHART 6



HEAD FOR STANDARD C. M. PIPE CULVERTS FLOWING FULL n=0.024

CHART 7

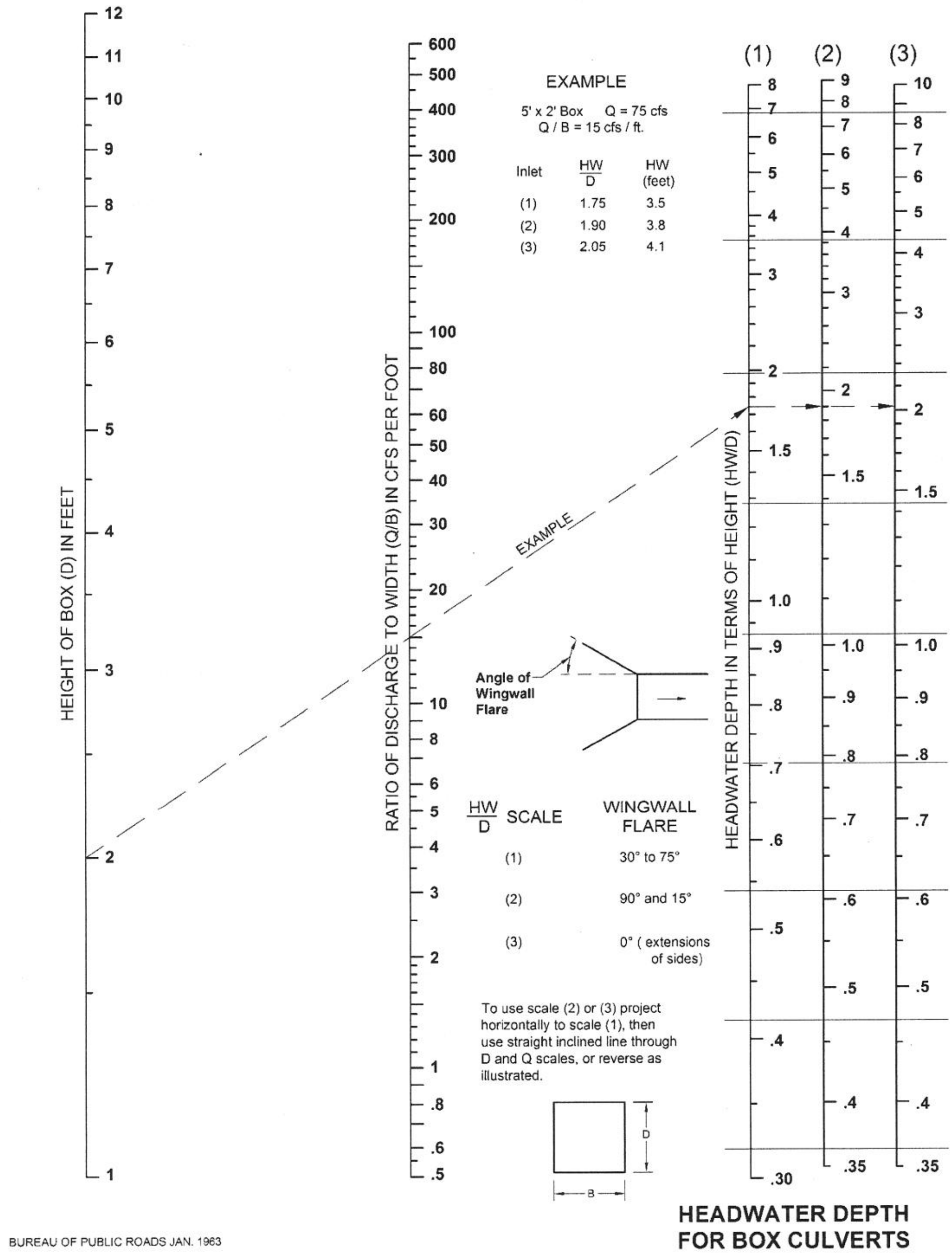


Diam.	n
5'	0.0328
7'	0.0320
10'	0.0311
15'	0.0302

HEAD FOR STRUCTURAL PLATE CORR. METAL PIPE CULVERTS FLOWING FULL
n = 0.0328 TO 0.0302

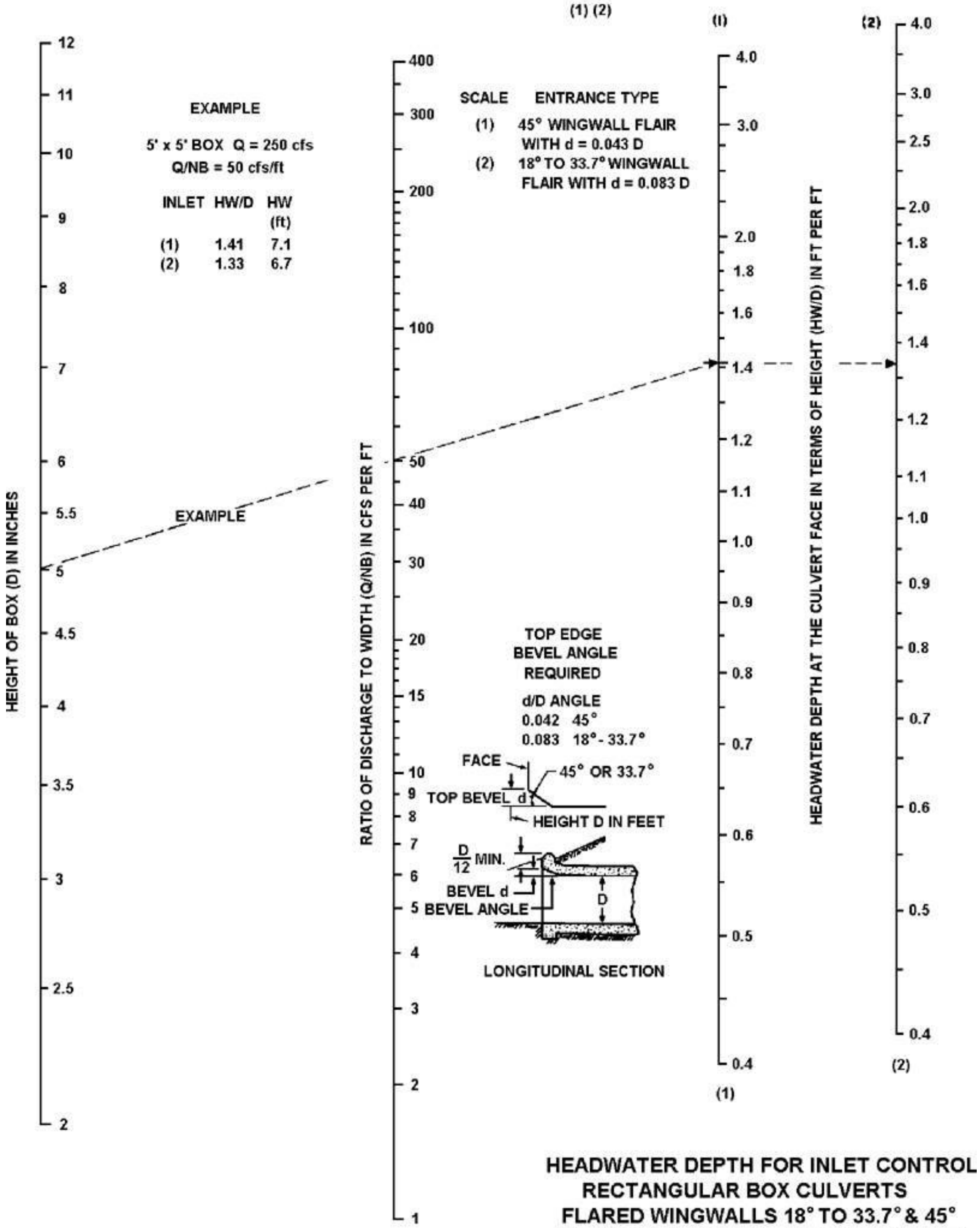
BUREAU OF PUBLIC ROADS JAN. 1963

CHART 8



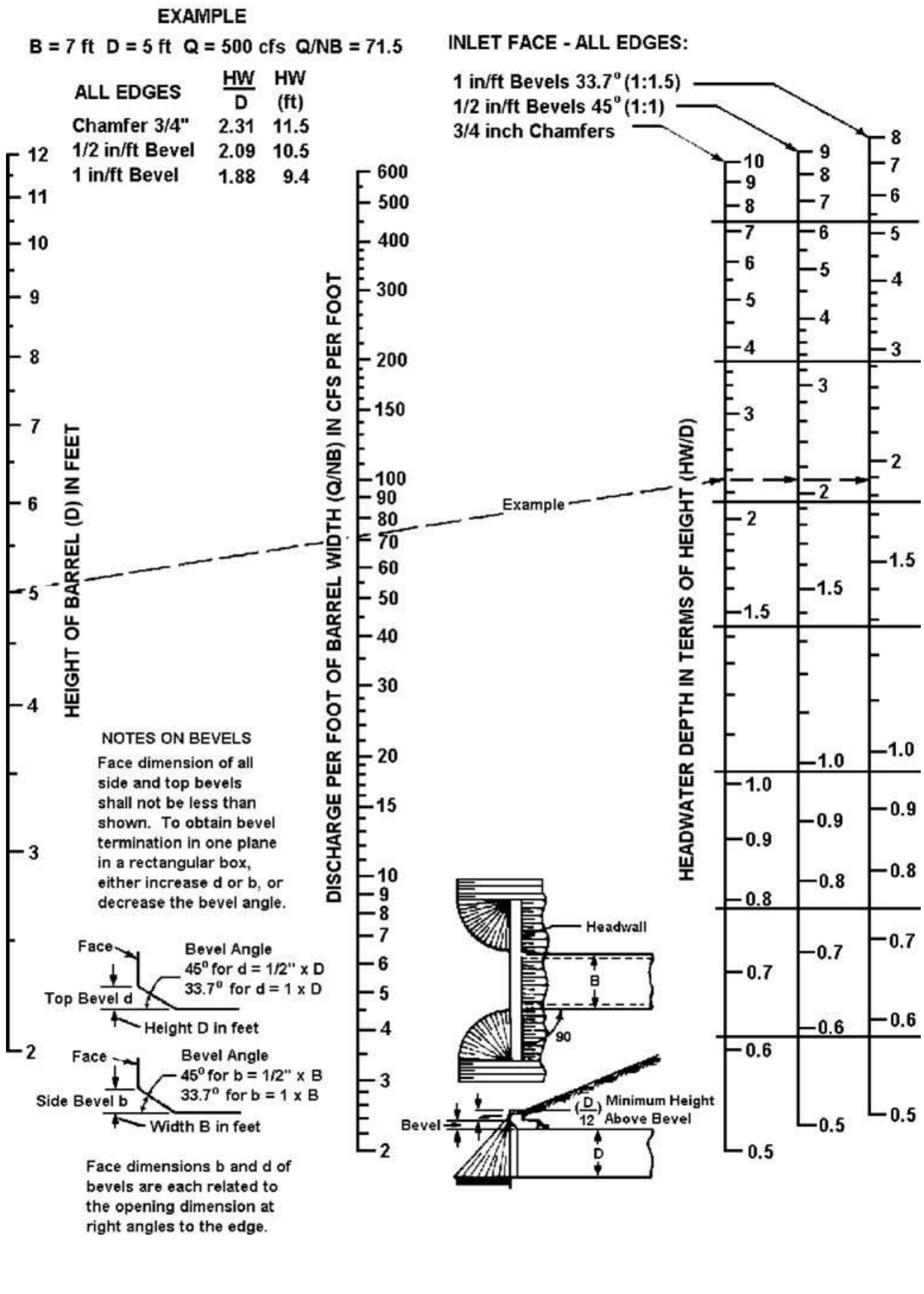
HEADWATER DEPTH FOR BOX CULVERTS WITH INLET CONTROL

CHART 9



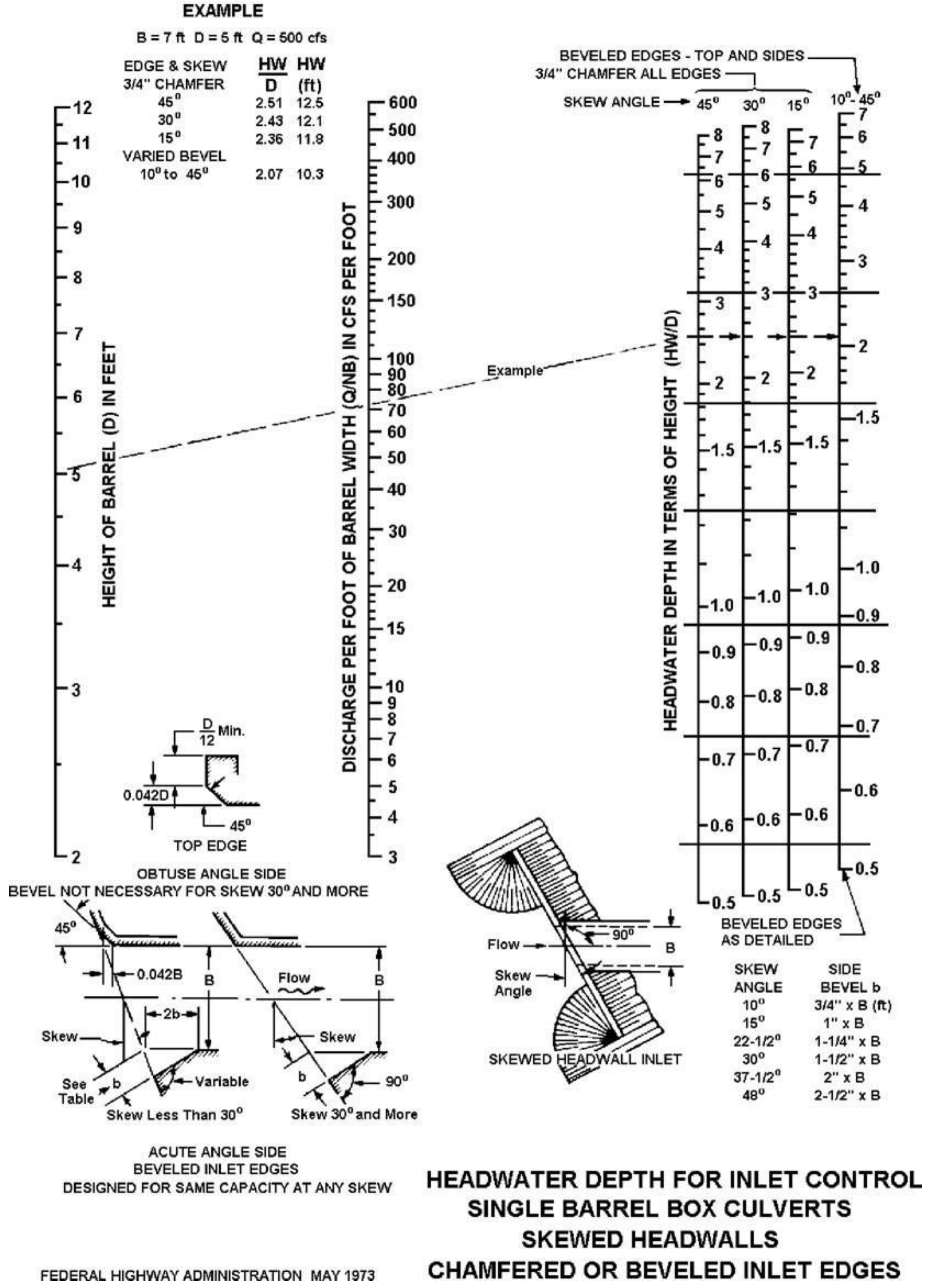
HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
FLARED WINGWALLS 18° TO 33.7° & 45°
WITH BEVELED EDGE AT TOP OF INLET

CHART 10



FEDERAL HIGHWAY ADMINSTRATION MAY 1973

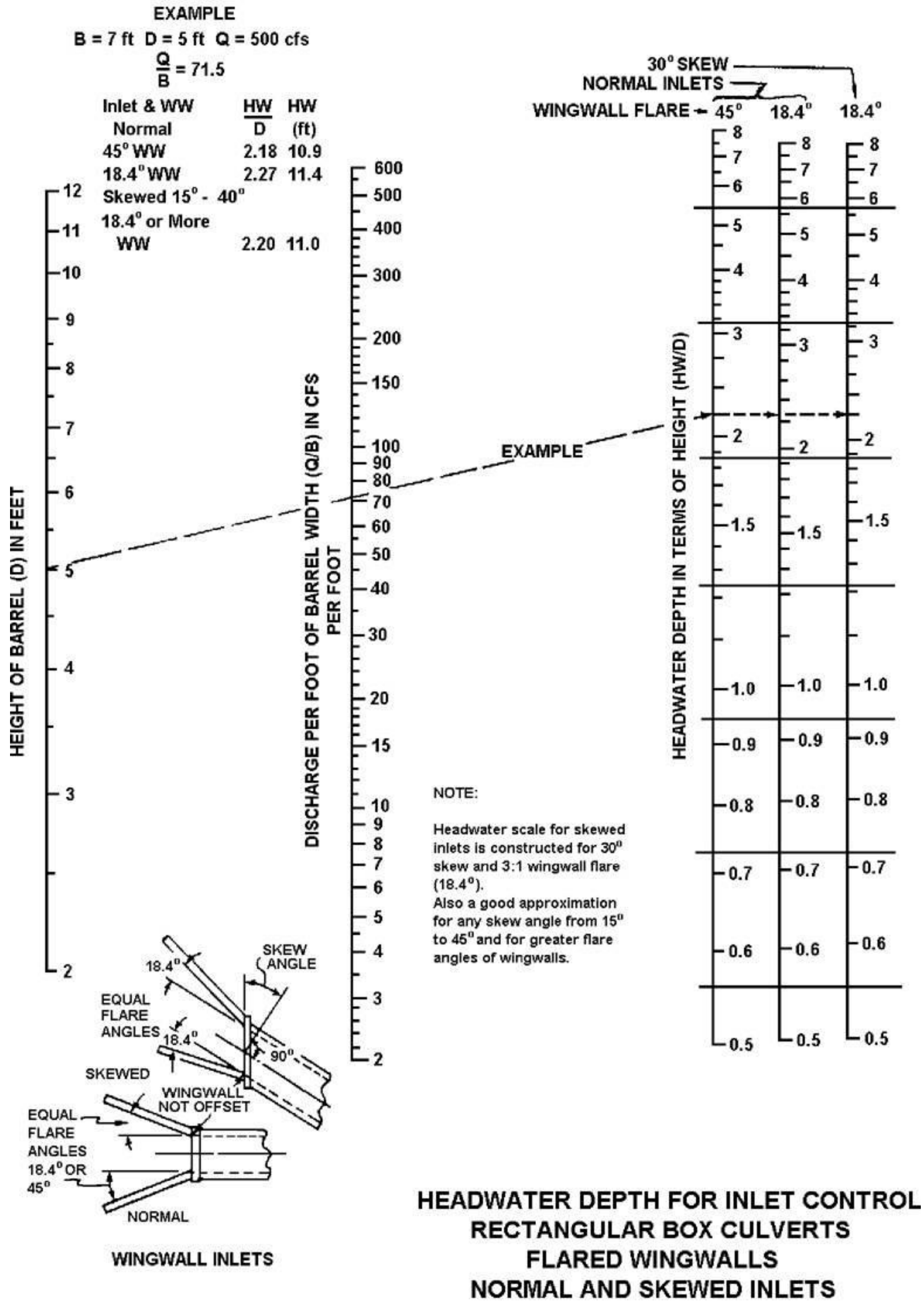
HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
90° HEADWALL
CHAMFERED OR BEVELED INLET EDGES



SKEW ANGLE	SIDE BEVEL b
10°	3/4" x B (ft)
15°	1" x B
22-1/2°	1-1/4" x B
30°	1-1/2" x B
37-1/2°	2" x B
48°	2-1/2" x B

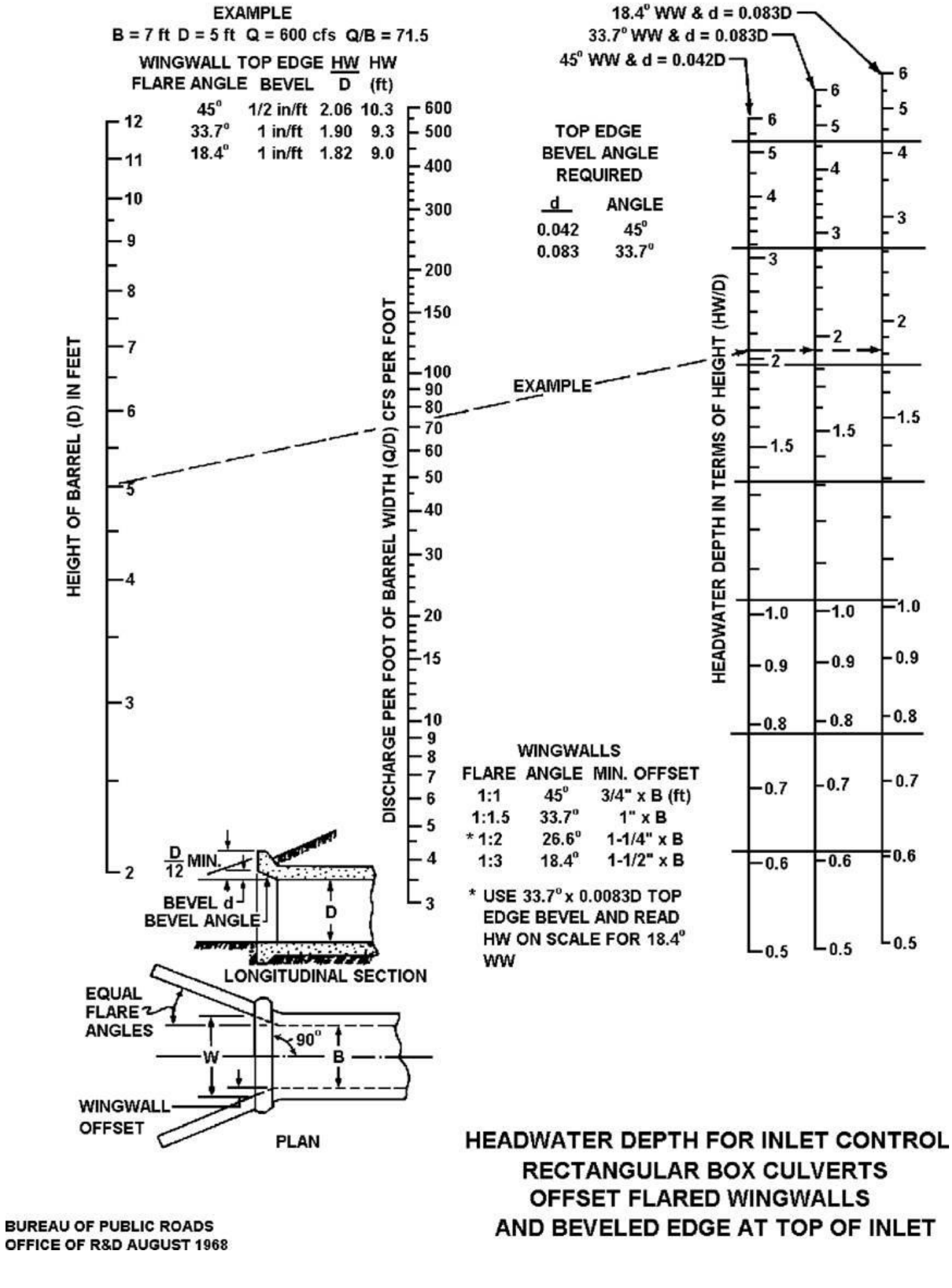
HEADWATER DEPTH FOR INLET CONTROL
SINGLE BARREL BOX CULVERTS
SKEWED HEADWALLS
CHAMFERED OR BEVELED INLET EDGES

CHART 12



HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
FLARED WINGWALLS
NORMAL AND SKEWED INLETS
3/4" CHAMFER AT TOP OF OPENING

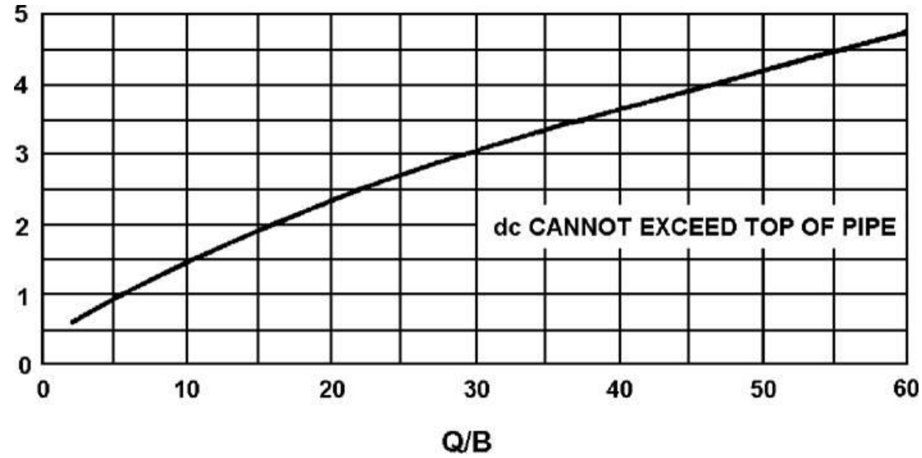
CHART 13

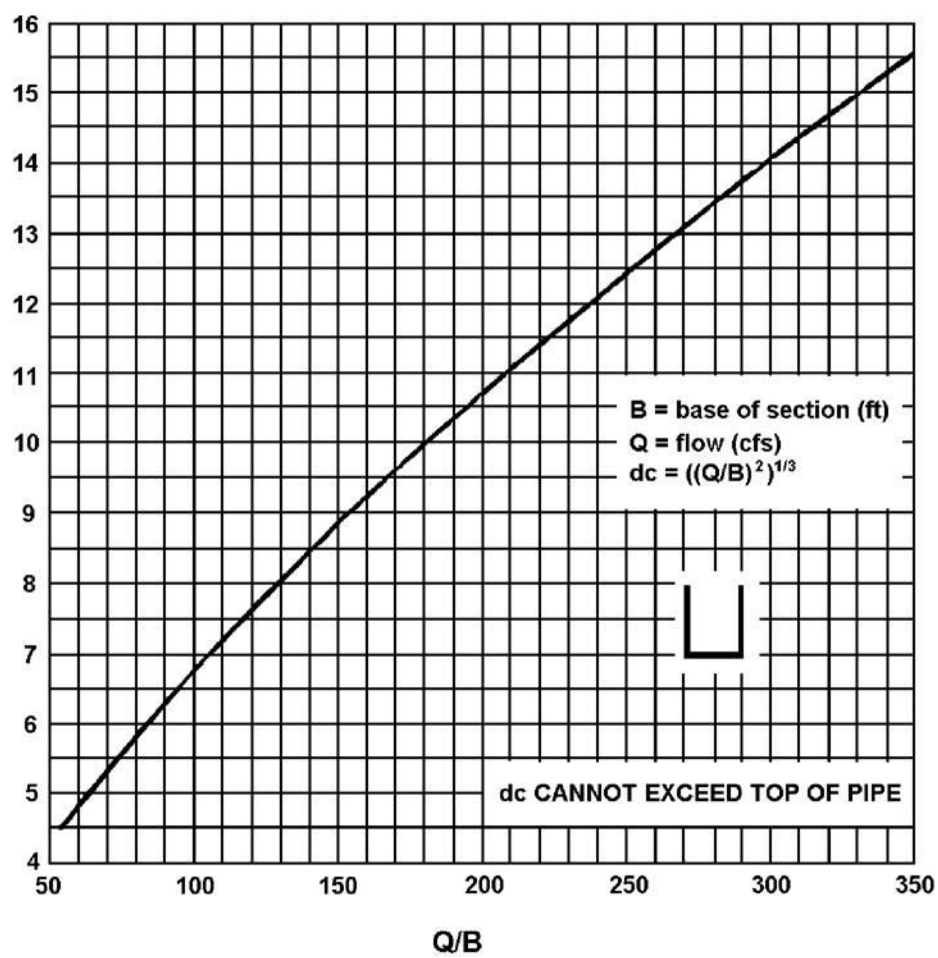


HEADWATER DEPTH FOR INLET CONTROL RECTANGULAR BOX CULVERTS OFFSET FLARED WINGWALLS AND BEVELED EDGE AT TOP OF INLET

BUREAU OF PUBLIC ROADS
OFFICE OF R&D AUGUST 1968

CHART 14

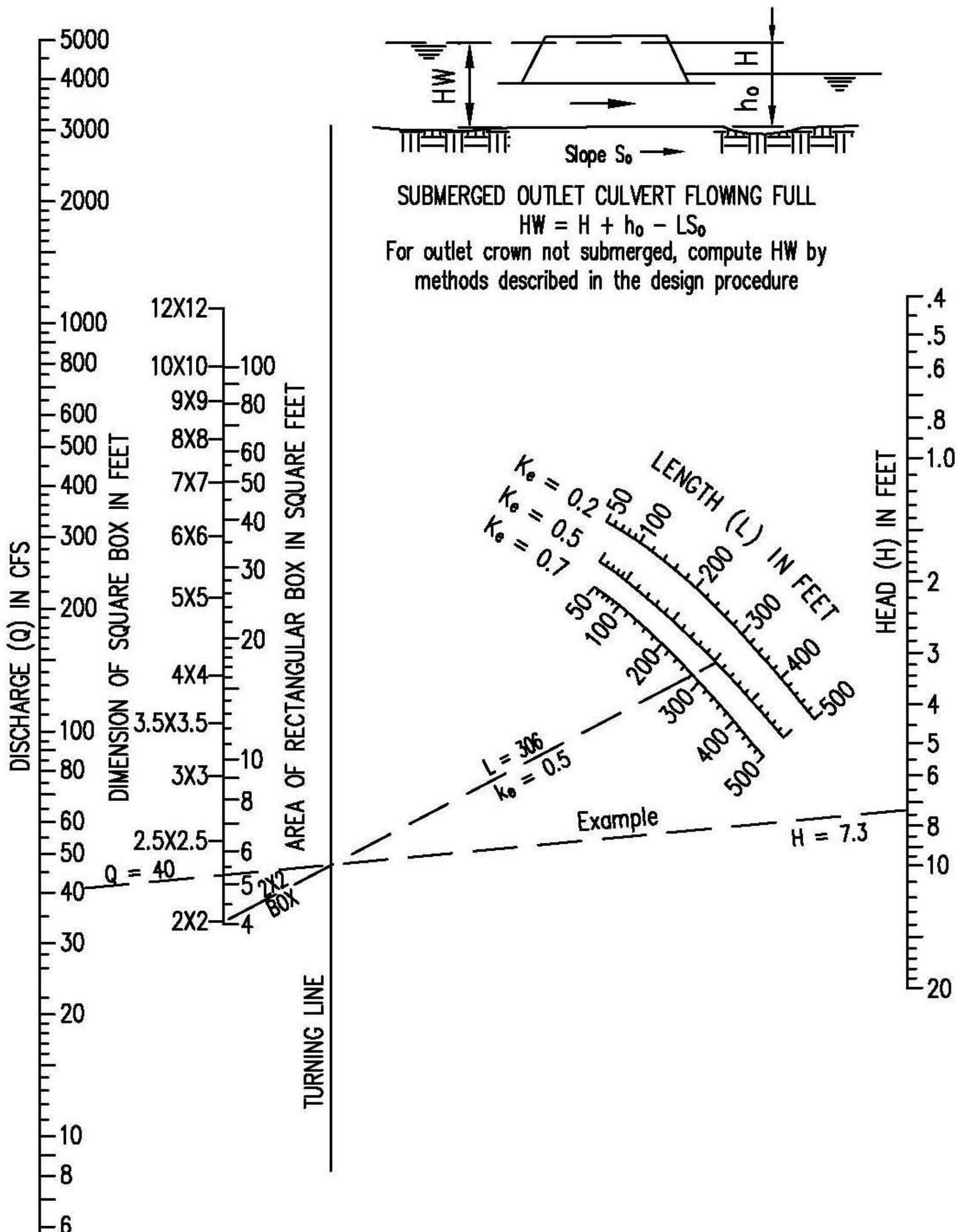




BUREAU OF PUBLIC ROADS JAN. 1963

CRITICAL DEPTH
RECTANGULAR SECTION

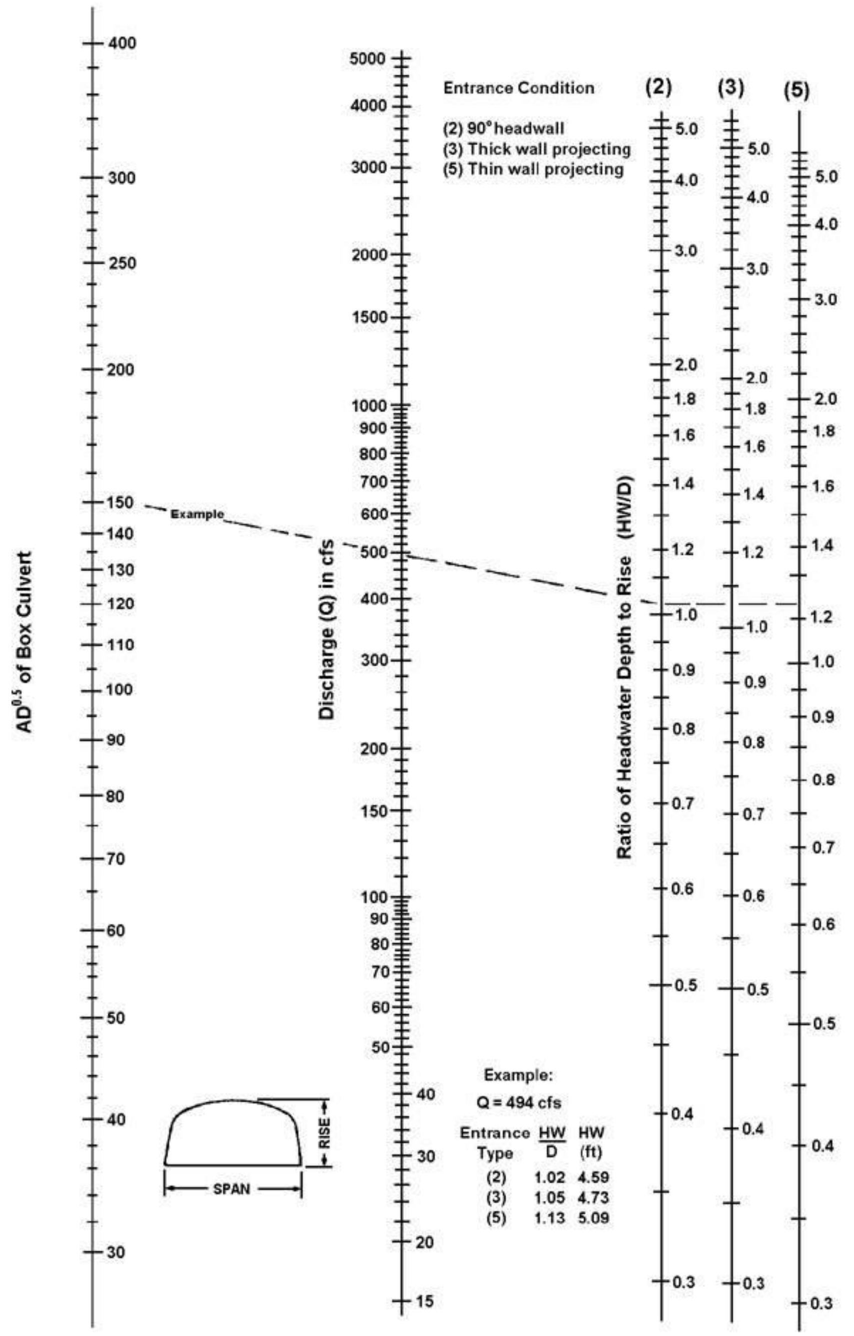
CHART 15



(Bureau of Public Roads Jan. 1963)

HEAD FOR
CONCRETE BOX CULVERTS
FLOWING FULL
n=0.012

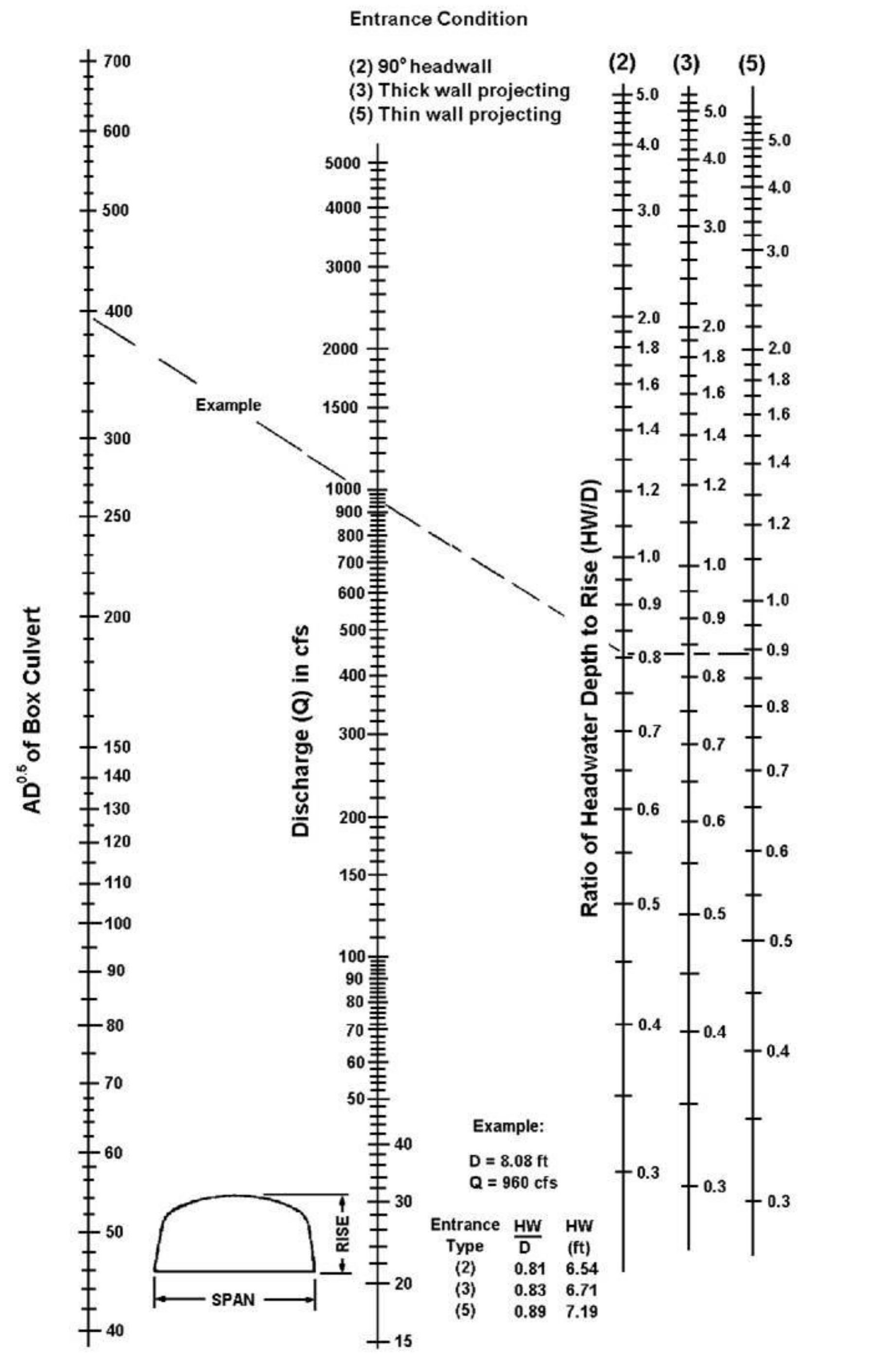
CHART 16



HEADWATER DEPTH
FOR C.M. BOX CULVERTS
RISE/SPAN < 0.3
WITH INLET CONTROL

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation.

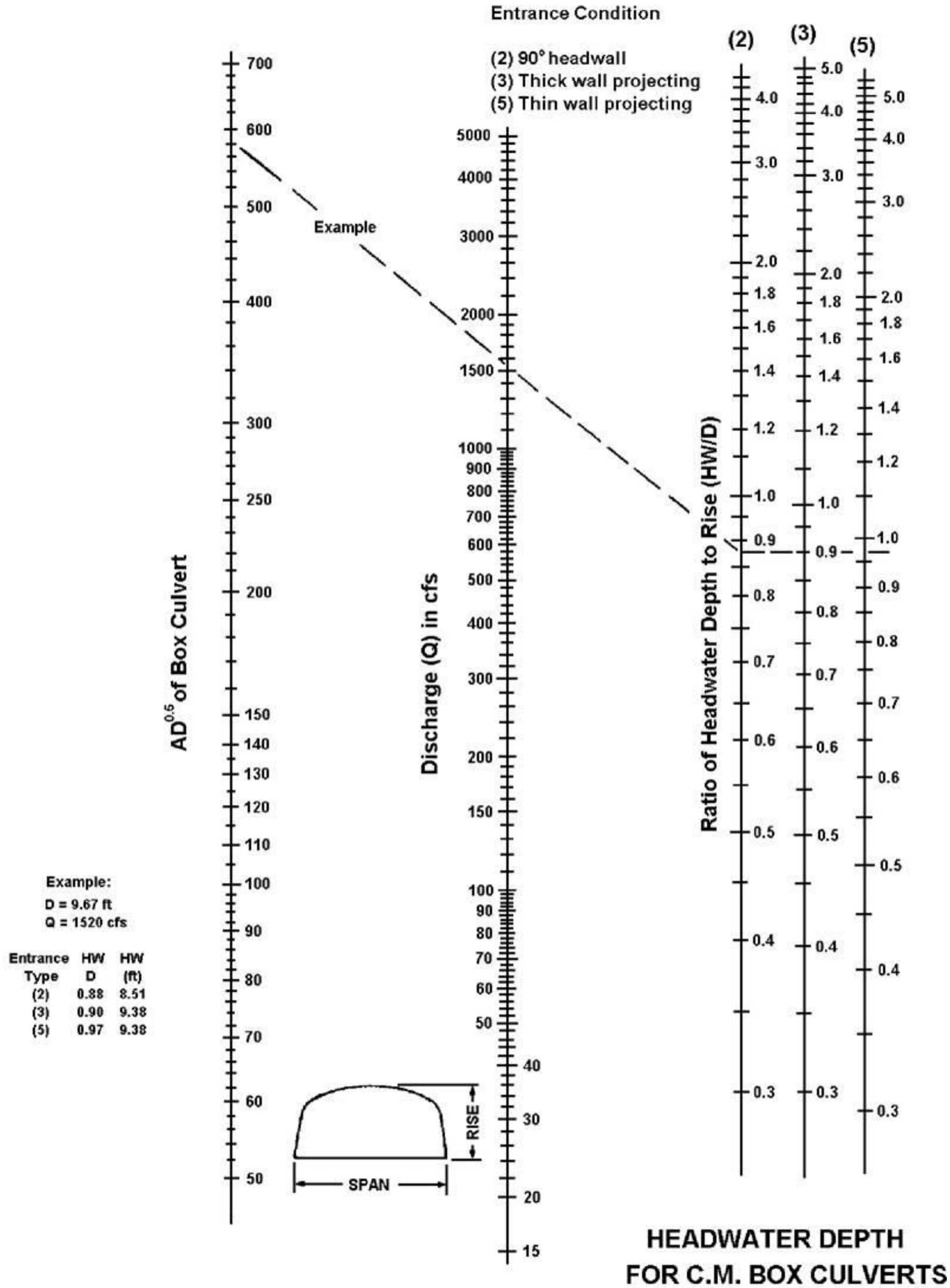
CHART 17



HEADWATER DEPTH
FOR C.M. BOX CULVERTS
0.3≤ RISE/SPAN < 0.4
WITH INLET CONTROL

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

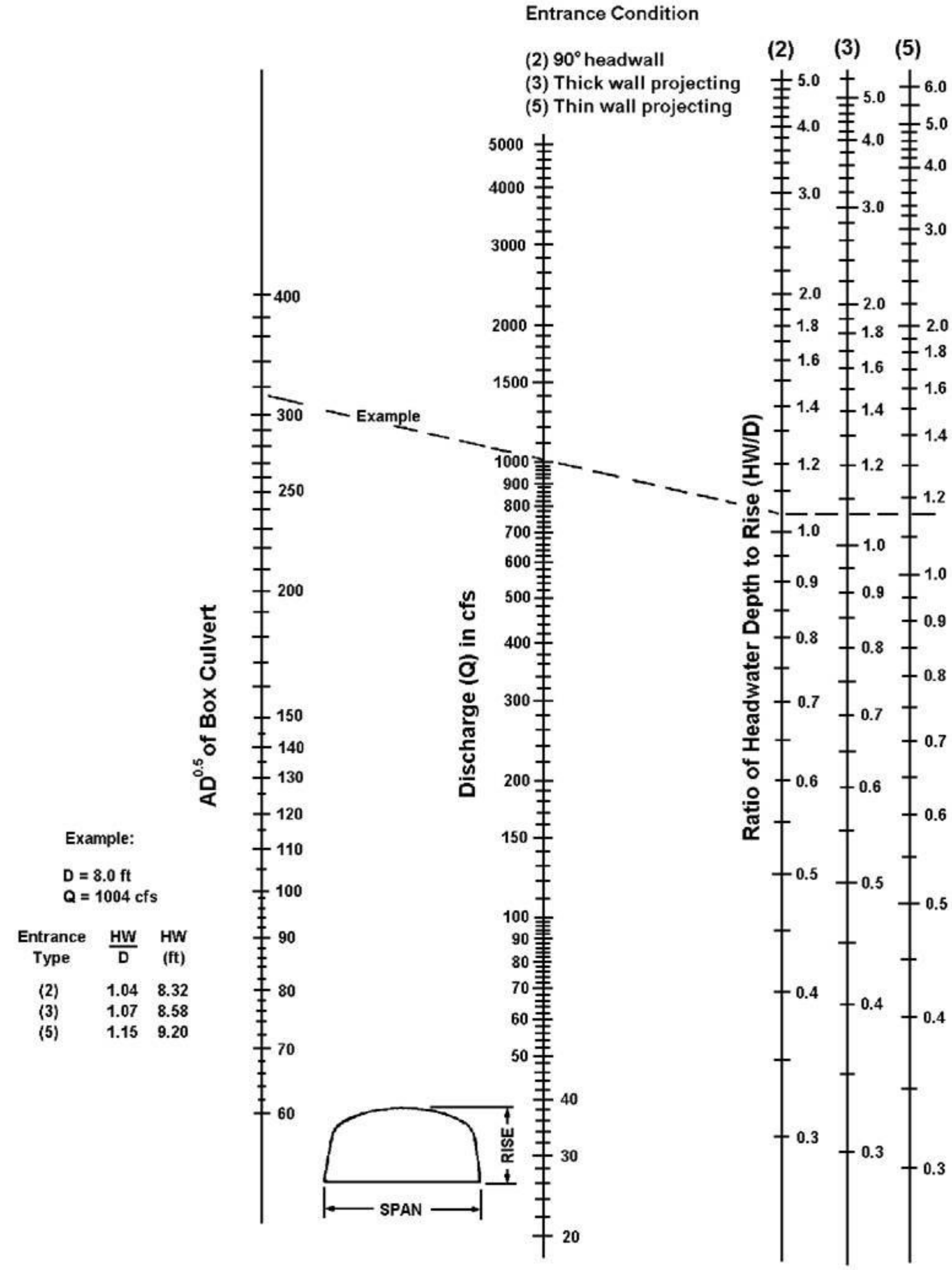
CHART 18



HEADWATER DEPTH FOR C.M. BOX CULVERTS $0.4 \leq$ RISE/SPAN < 0.5 WITH INLET CONTROL

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

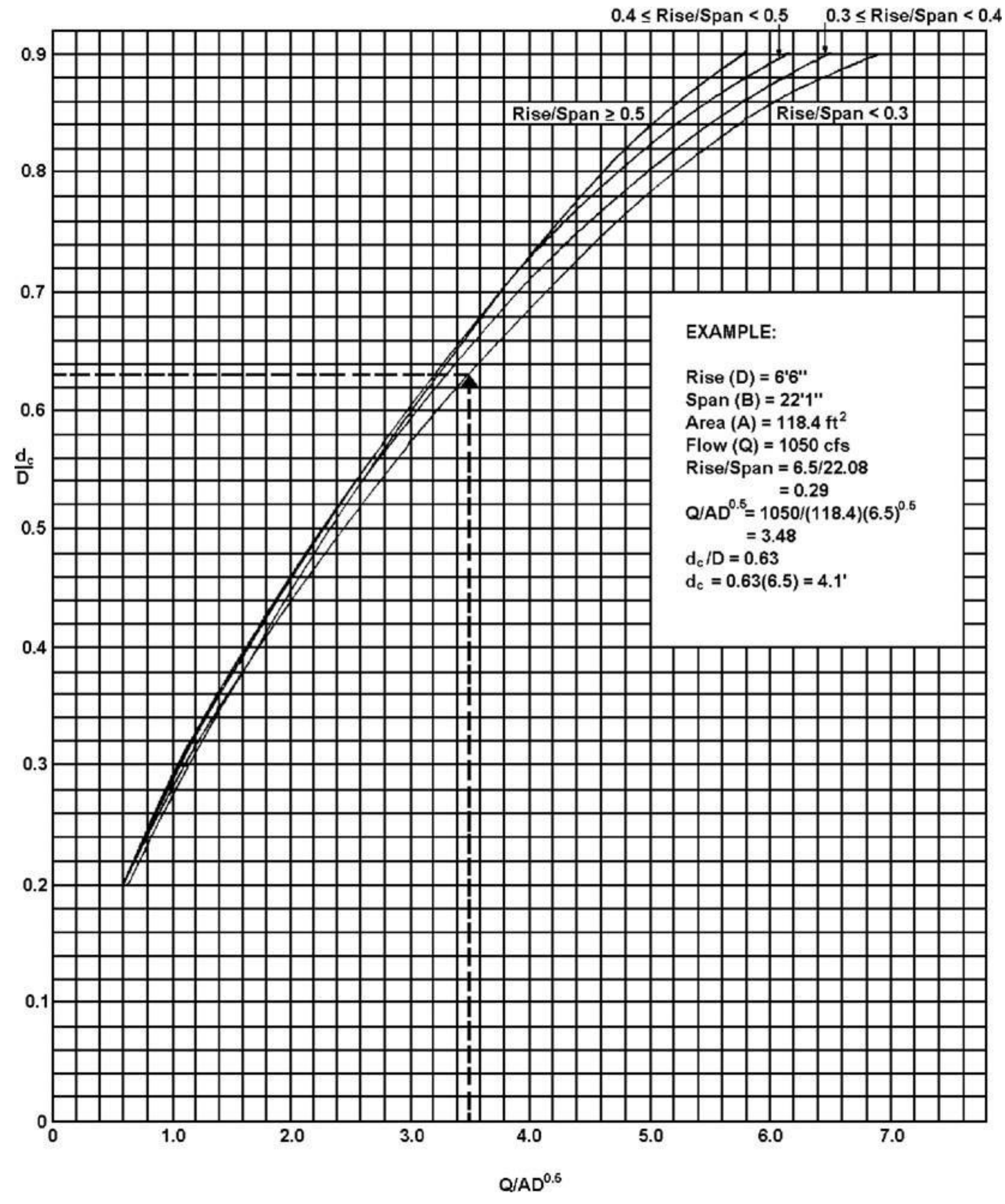
CHART 19



Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation.

HEADWATER DEPTH
FOR C.M. BOX CULVERTS
0.5 ≤ RISE/SPAN
WITH INLET CONTROL

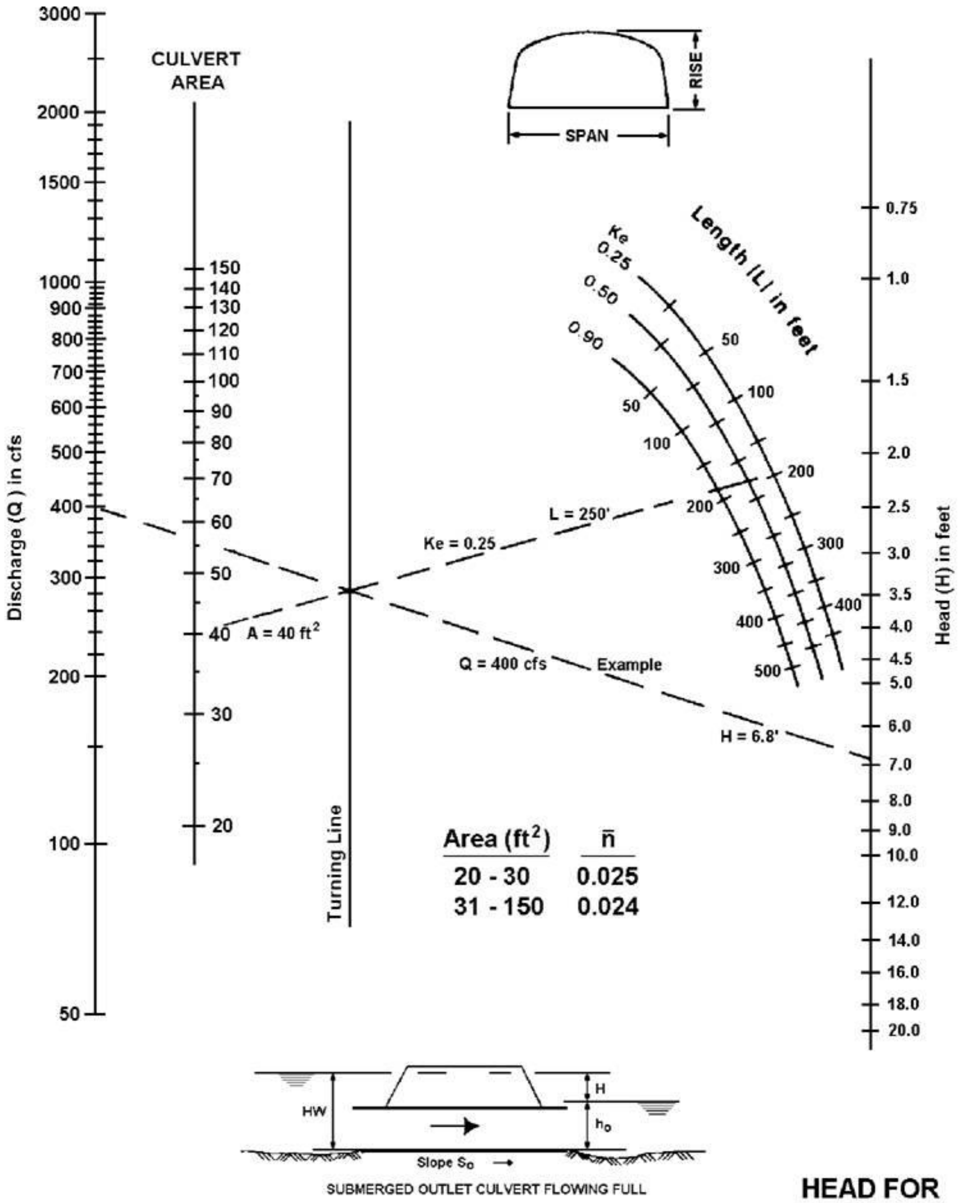
CHART 20



DIMENSIONLESS CRITICAL DEPTH

FOR C.M. BOX CULVERTS

CHART 21



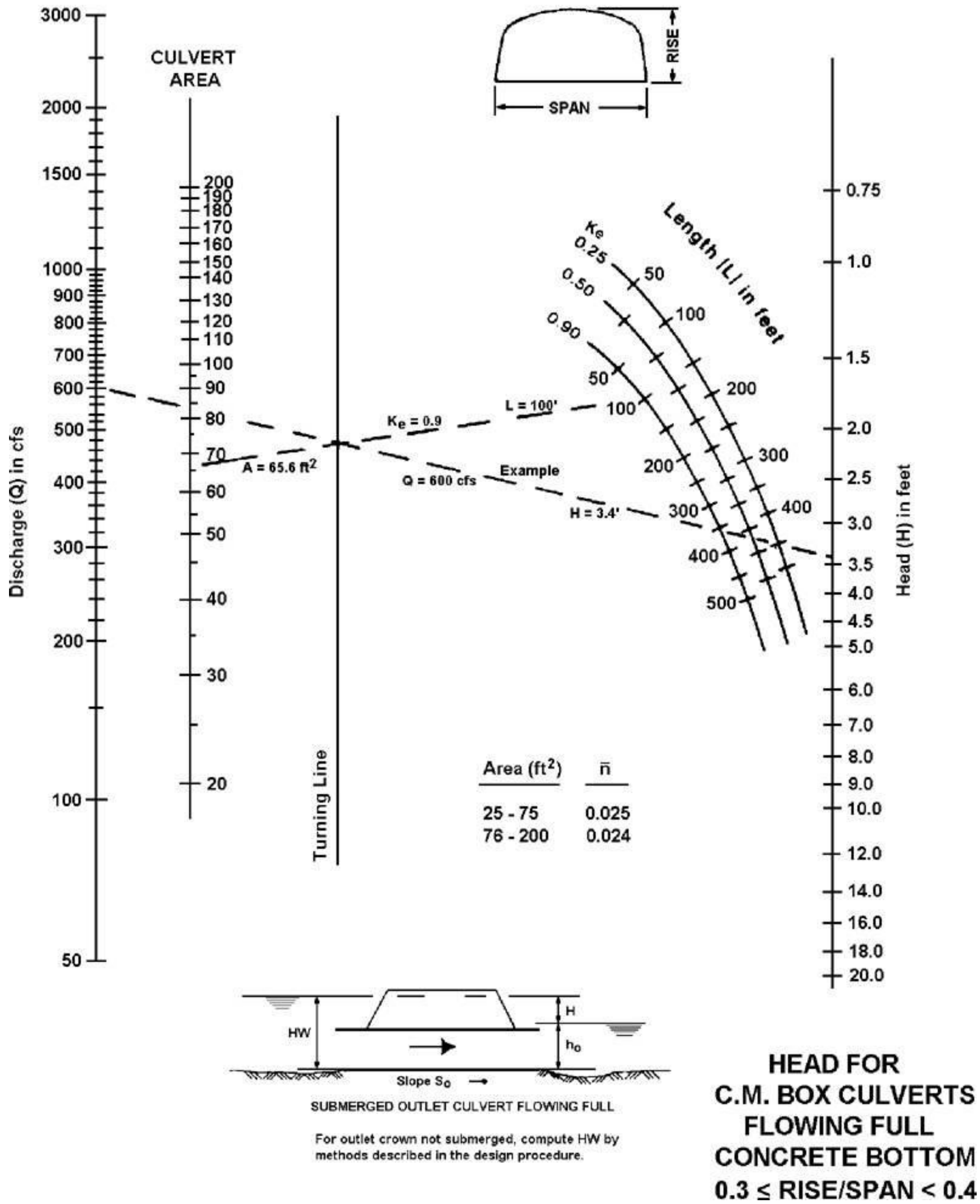
Area (ft^2)	$\bar{n}$
20 - 30	0.025
31 - 150	0.024

For outlet crown not submerged, compute HW by methods described in the design procedure.

HEAD FOR C.M. BOX CULVERTS FLOWING FULL CONCRETE BOTTOM RISE/SPAN < 0.3

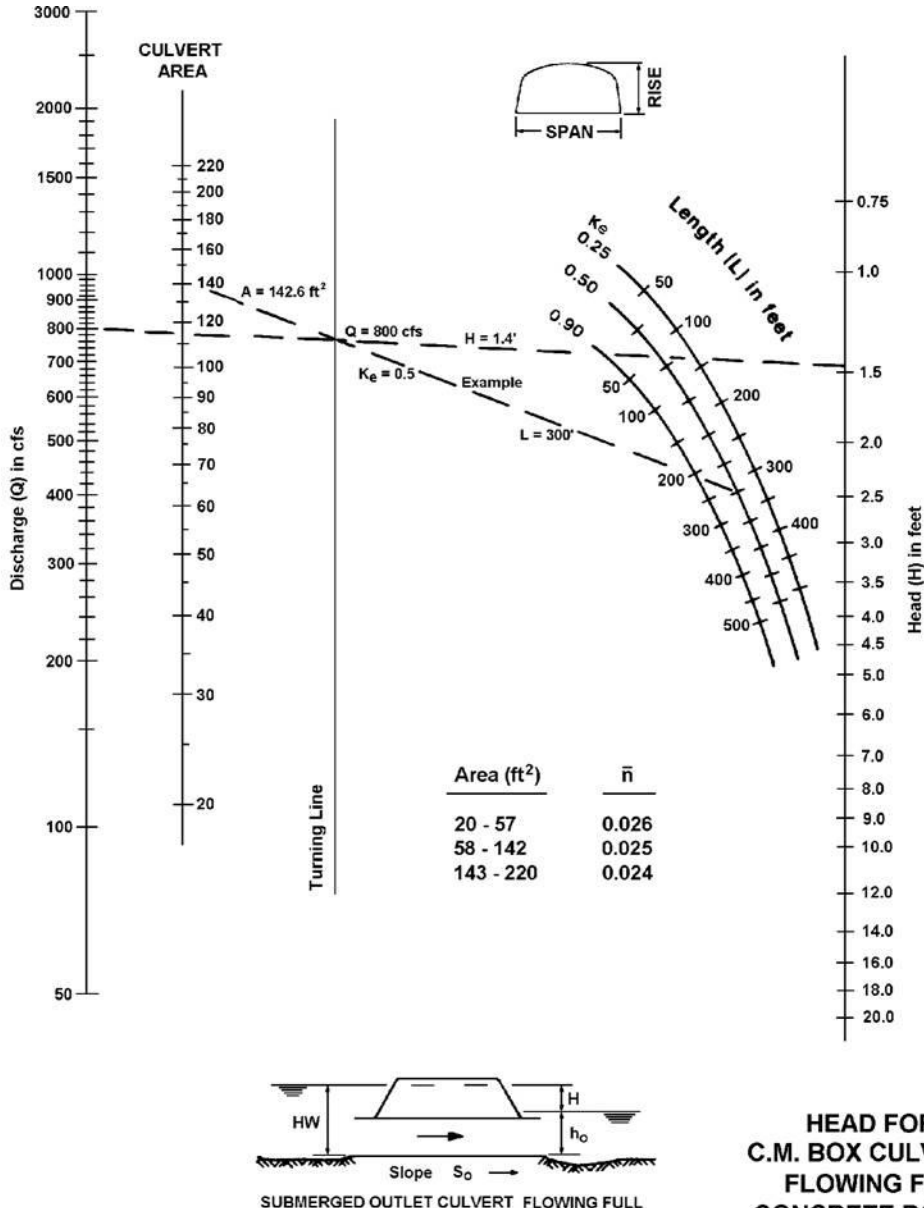
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 22



CULVERT AREA
RISE
SPAN
Discharge (Q) in cfs
Turning Line
Head (H) in feet
Length (L) in feet
Ke
0.25
0.50
0.90
L = 100'
Ke = 0.9
A = 65.6 ft²
Q = 600 cfs
Example
H = 3.4'
Area (ft²) n̄
25 - 75 0.025
76 - 200 0.024
HW
H
h₀
Slope S₀
SUBMERGED OUTLET CULVERT FLOWING FULL
For outlet crown not submerged, compute HW by methods described in the design procedure.
HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.3 ≤ RISE/SPAN < 0.4

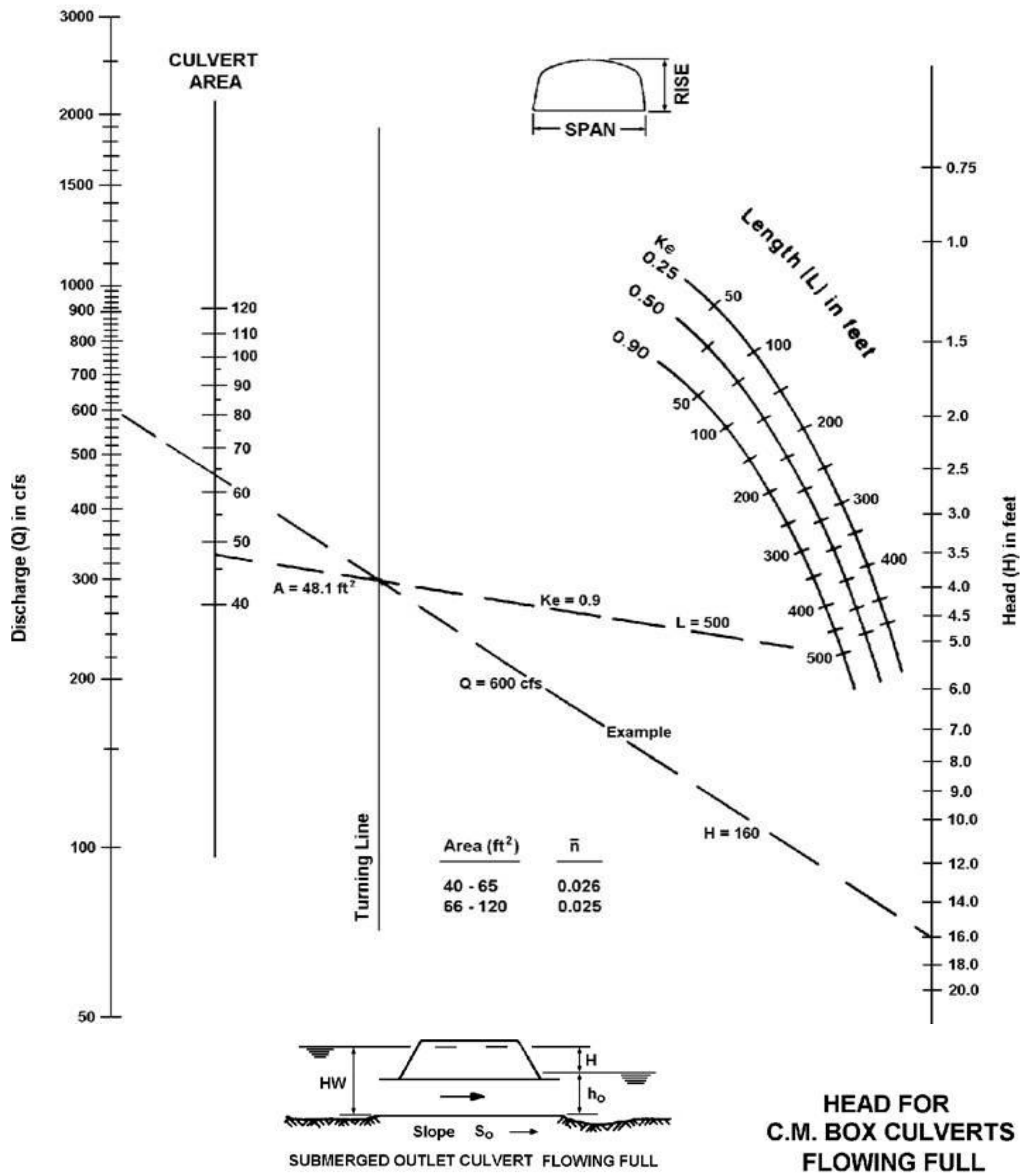
CHART 23



HEAD FOR C.M. BOX CULVERTS FLOWING FULL CONCRETE BOTTOM $0.4 \leq$ RISE/SPAN < 0.5

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

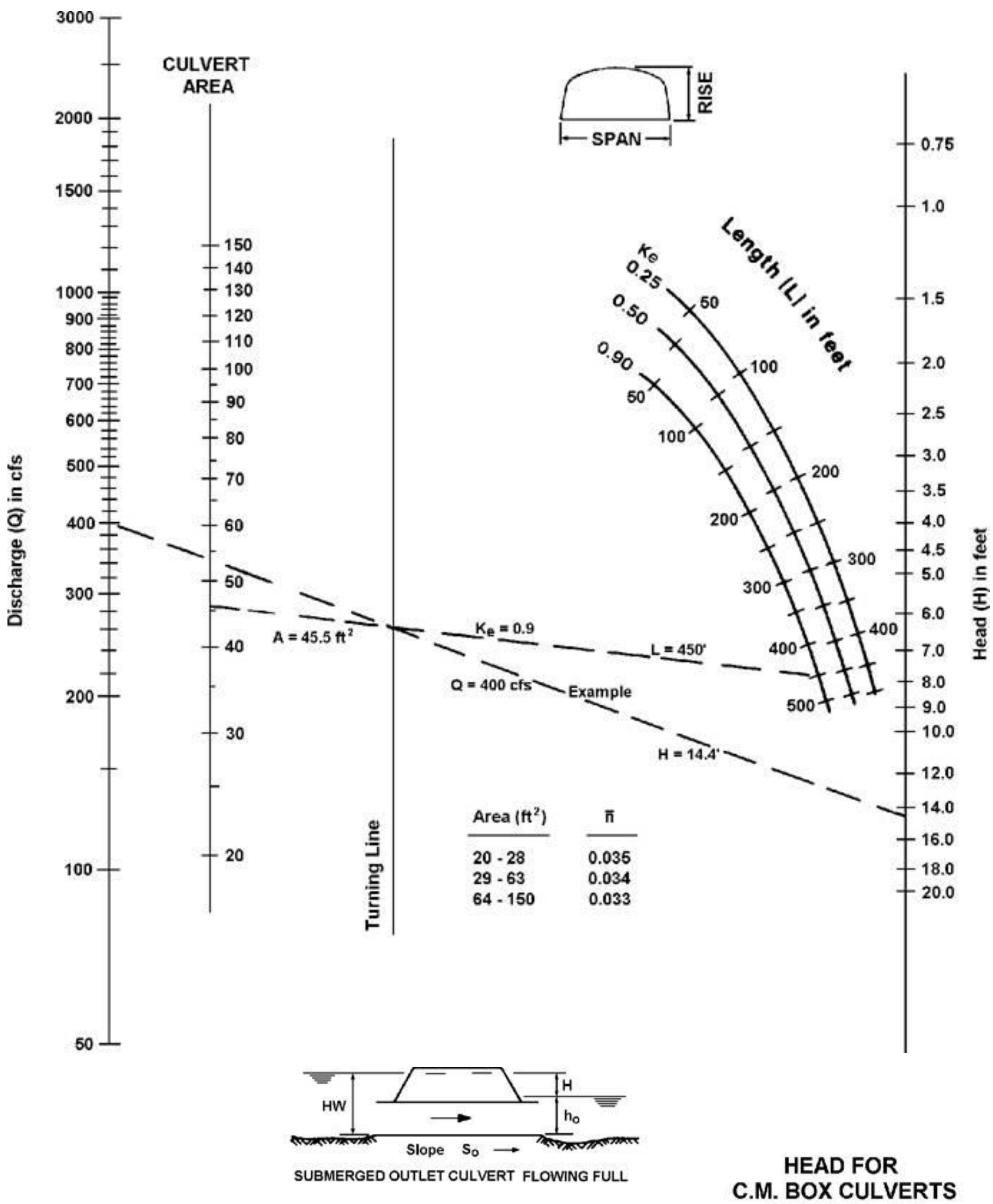
CHART 24



Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

HEAD FOR C.M. BOX CULVERTS FLOWING FULL CONCRETE BOTTOM $0.5 \leq$ RISE/SPAN

CHART 25

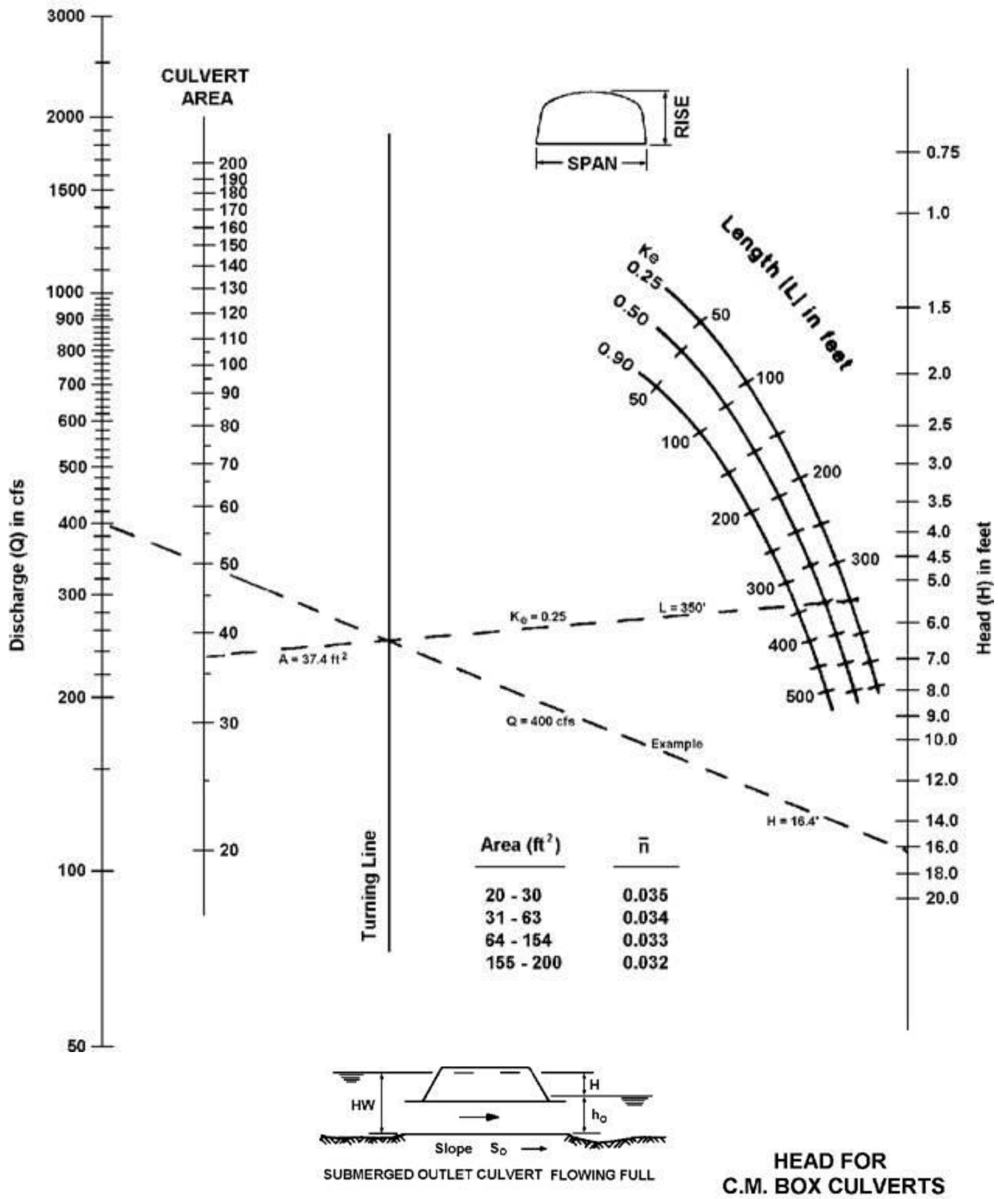


Area (ft²)	n̄
20 - 28	0.035
29 - 63	0.034
64 - 150	0.033

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

HEAD FOR
C.M. BOX CULVERTS
FLOWING FULL
CORRUGATED METAL BOTTOM
0.3< RISE/SPAN

CHART 26

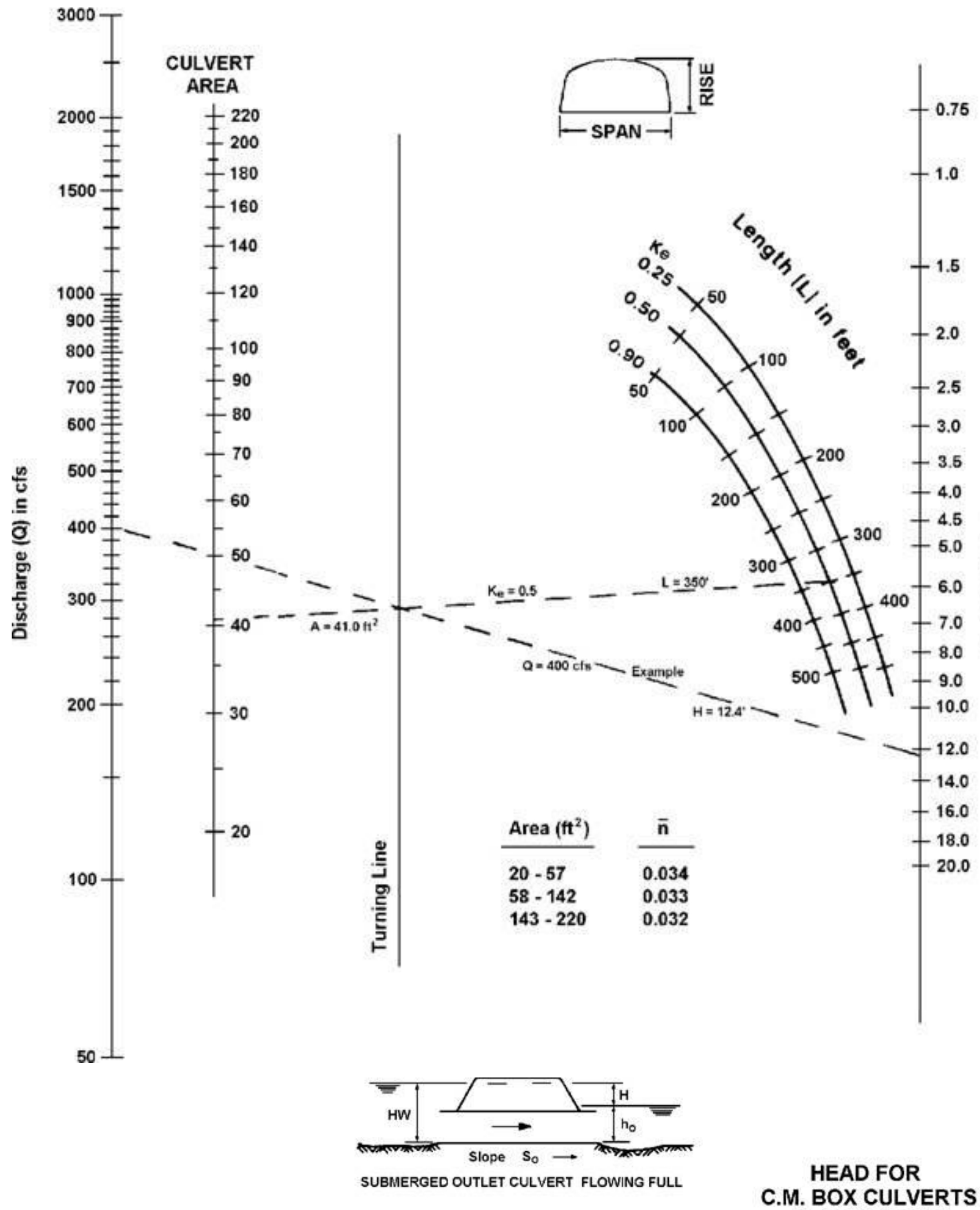


Area (ft²)	n̄
20 - 30	0.035
31 - 63	0.034
64 - 154	0.033
155 - 200	0.032

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

HEAD FOR C.M. BOX CULVERTS FLOWING FULL CORRUGATED METAL BOTTOM $0.4 \leq$ RISE/SPAN < 0.5

CHART 27

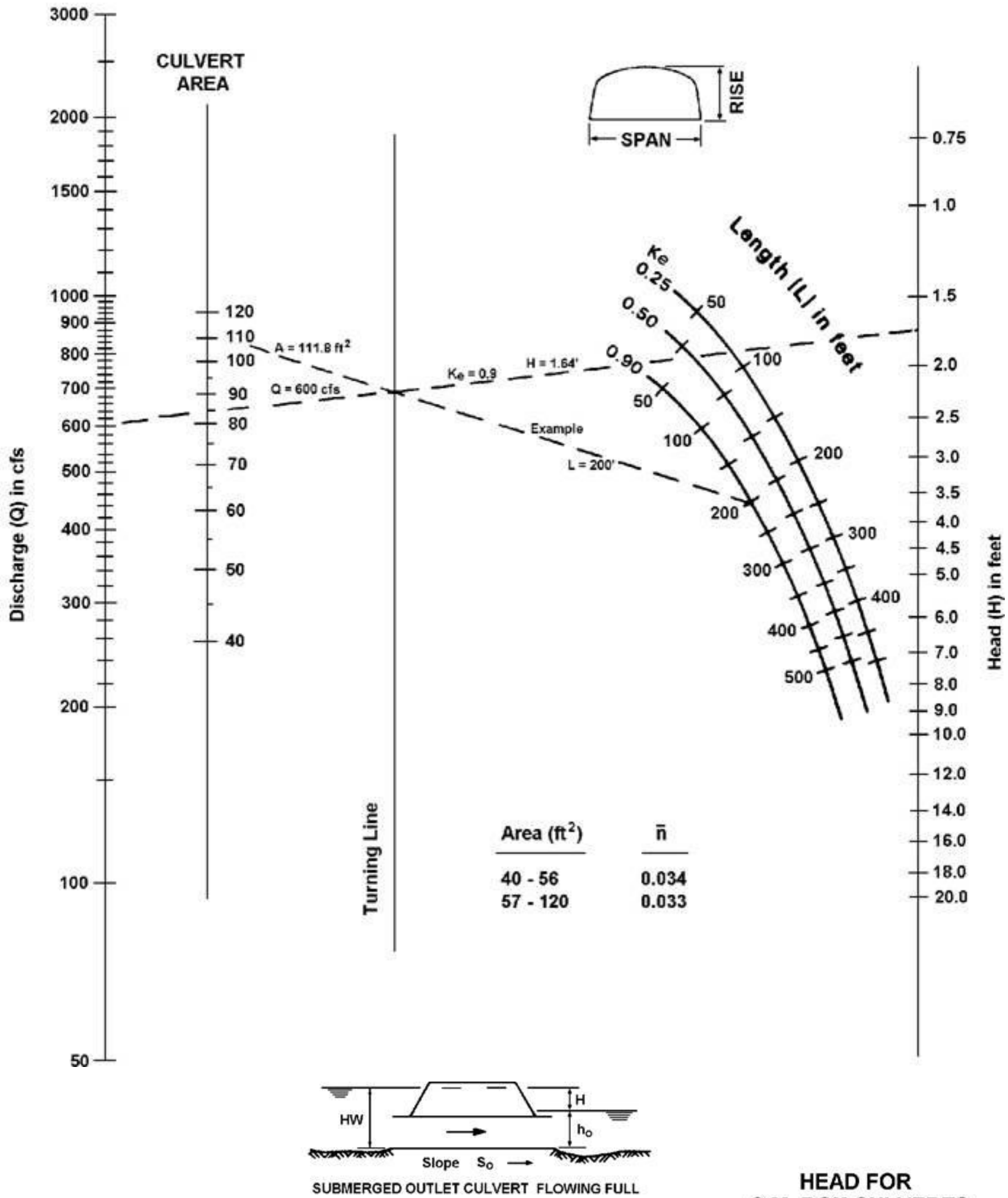


Area (ft^2)	$\bar{n}$
20 - 57	0.034
58 - 142	0.033
143 - 220	0.032

Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

HEAD FOR C.M. BOX CULVERTS FLOWING FULL CORRUGATED METAL BOTTOM $0.4 \leq$ RISE/SPAN < 0.5

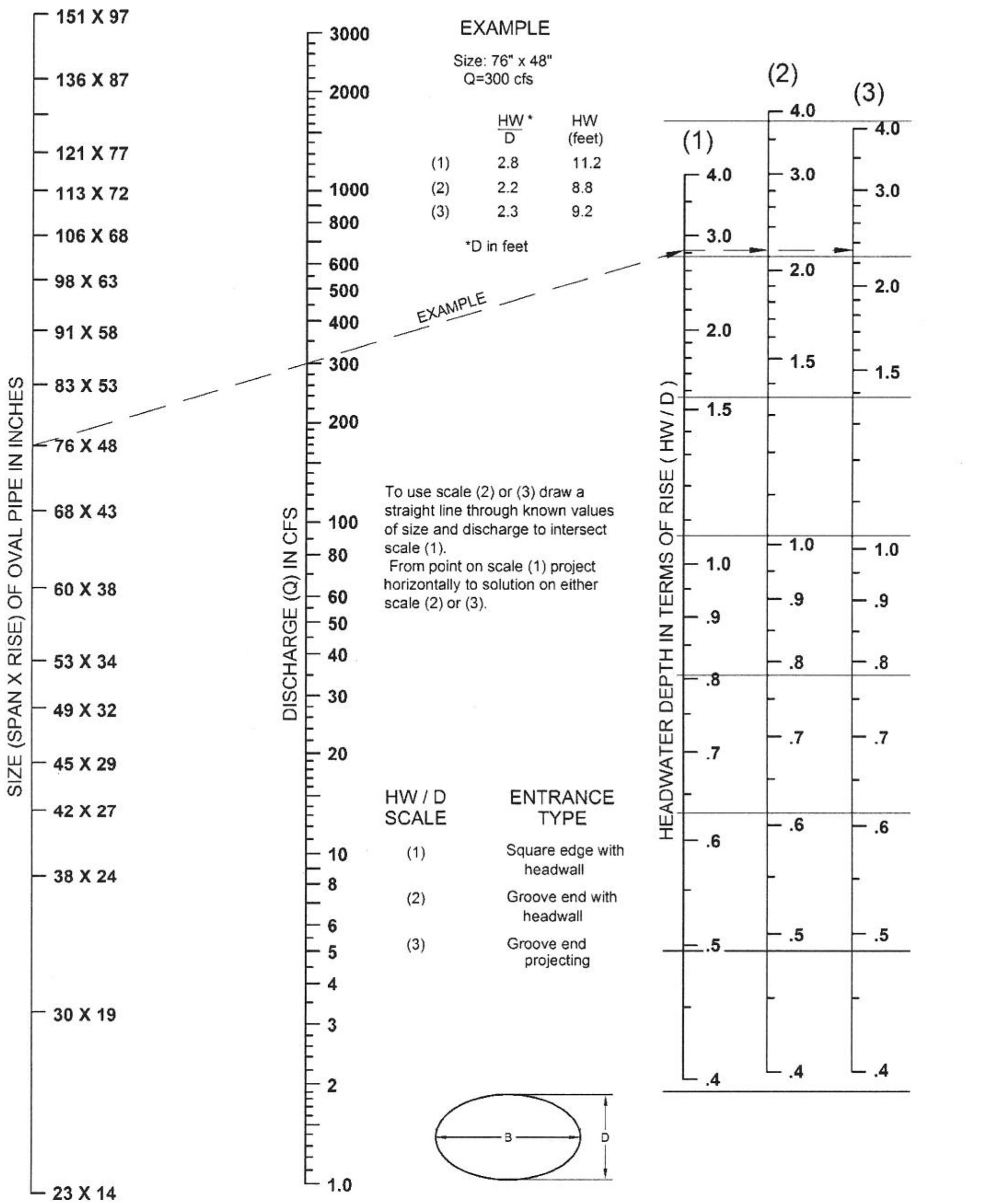
CHART 28



Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

HEAD FOR C.M. BOX CULVERTS FLOWING FULL CORRUGATED METAL BOTTOM $0.5 \leq$ RISE/SPAN

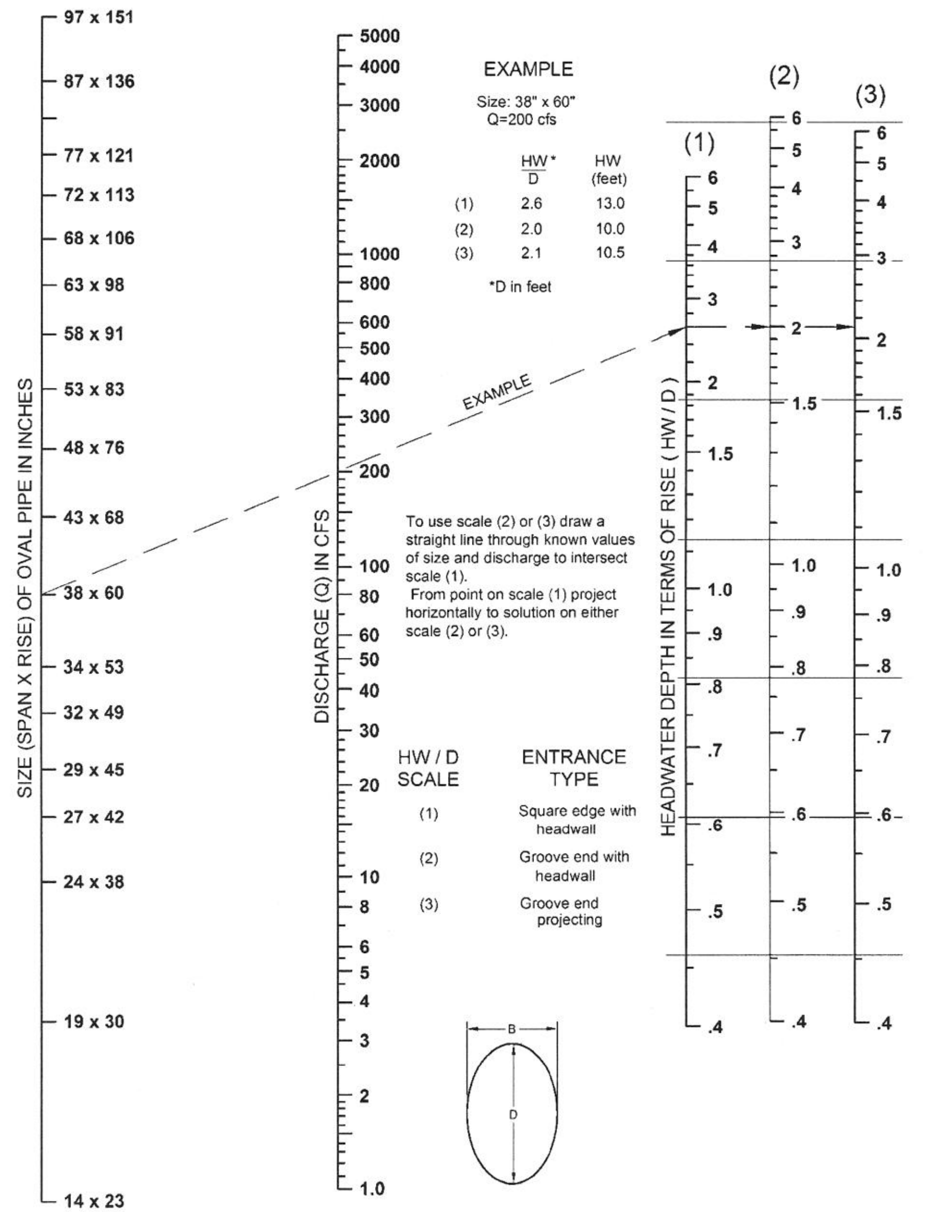
CHART 29



HEADWATER DEPTH FOR OVAL CONCRETE PIPE CULVERTS LONG AXIS HORIZONTAL WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

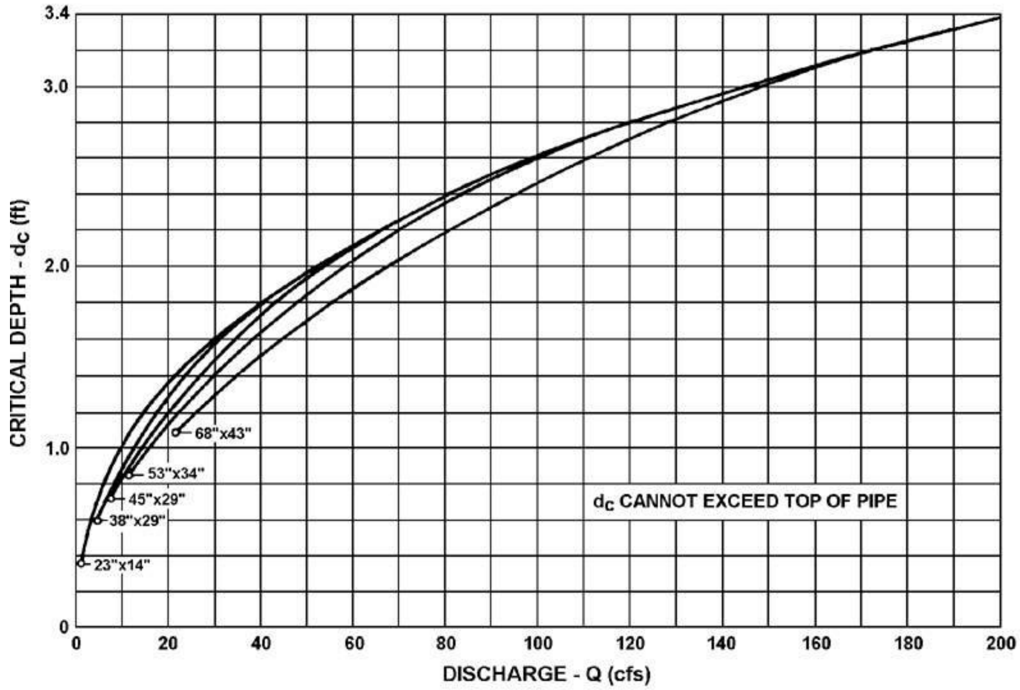
CHART 30

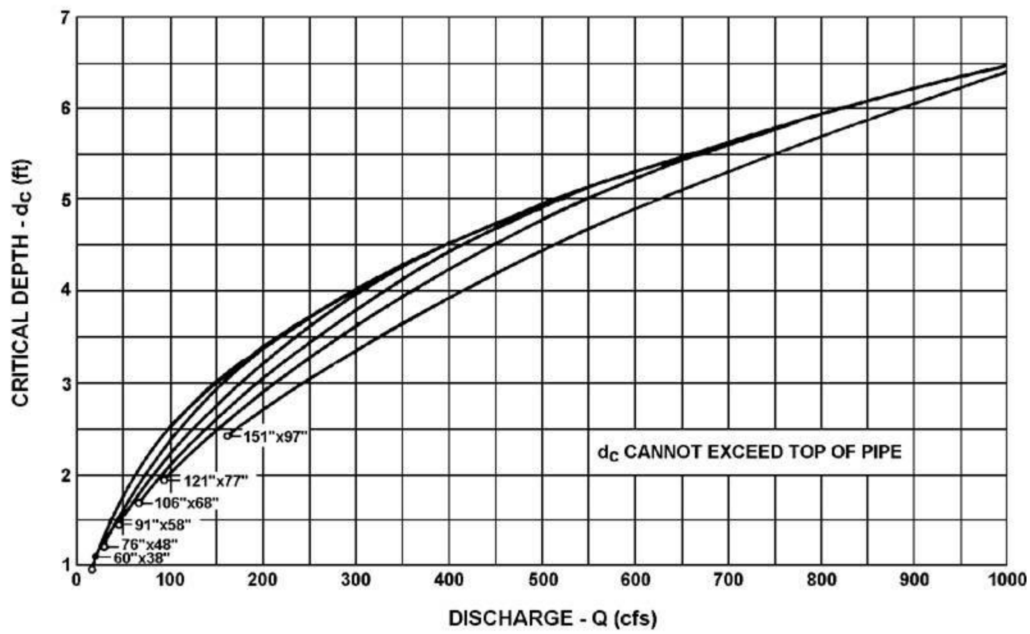


BUREAU OF PUBLIC ROADS JAN. 1963

HEADWATER DEPTH FOR OVAL CONCRETE PIPE CULVERTS LONG AXIS VERTICAL WITH INLET CONTROL

CHART 31

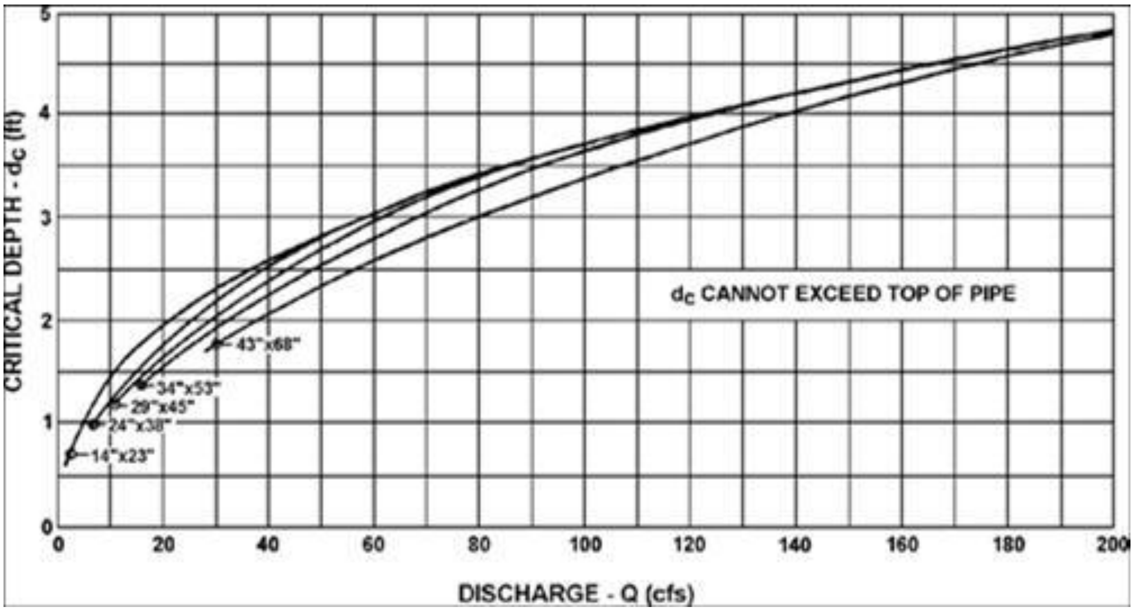


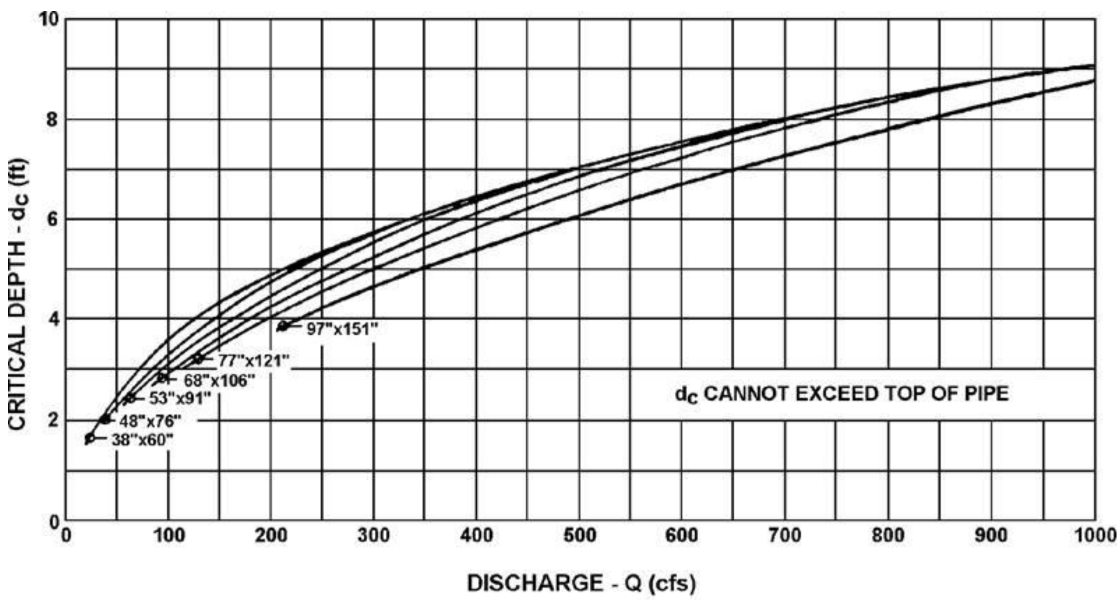


BUREAU OF PUBLIC ROADS JAN. 1964

CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS HORIZONTAL

CHART 32

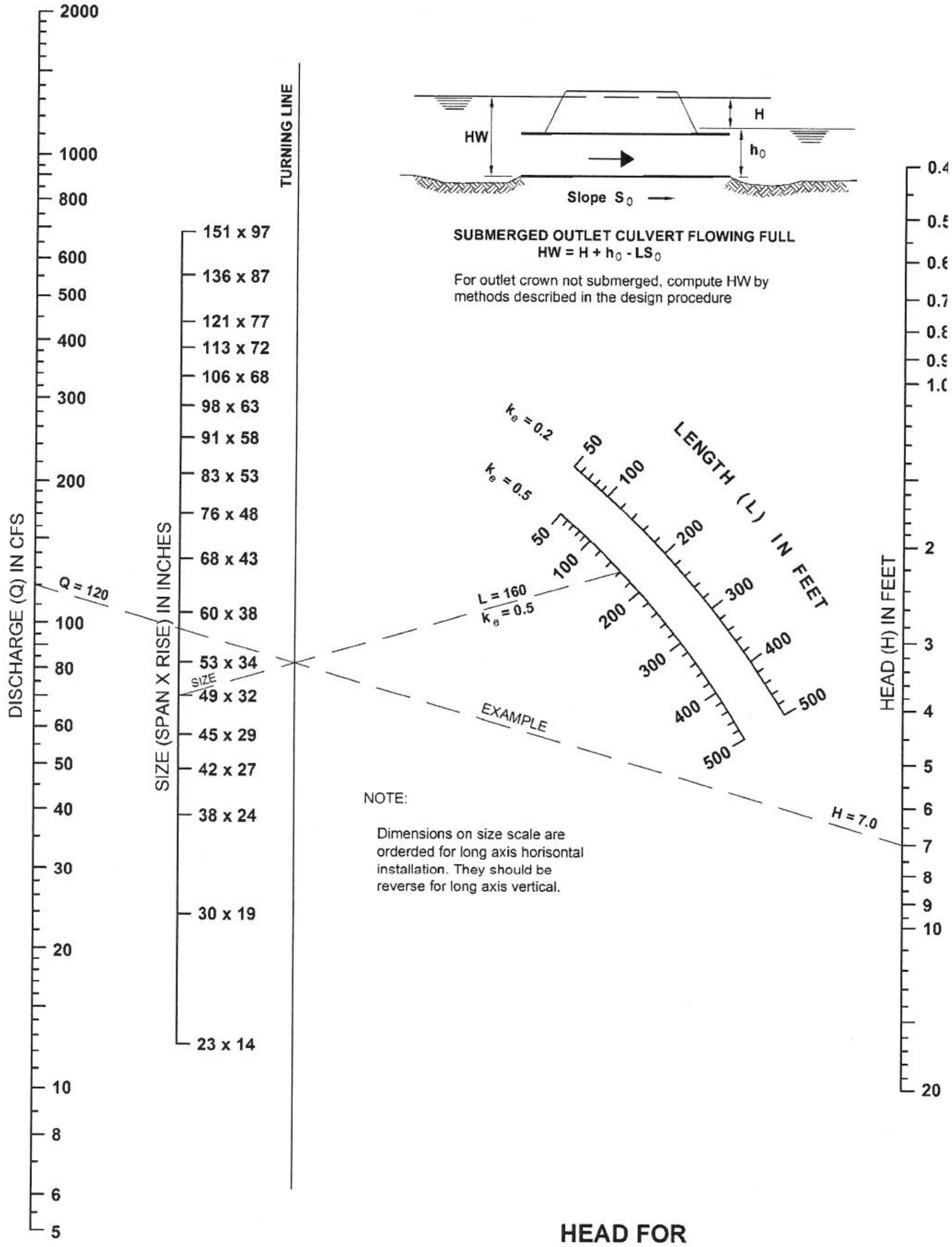




BUREAU OF PUBLIC ROADS JAN. 1964

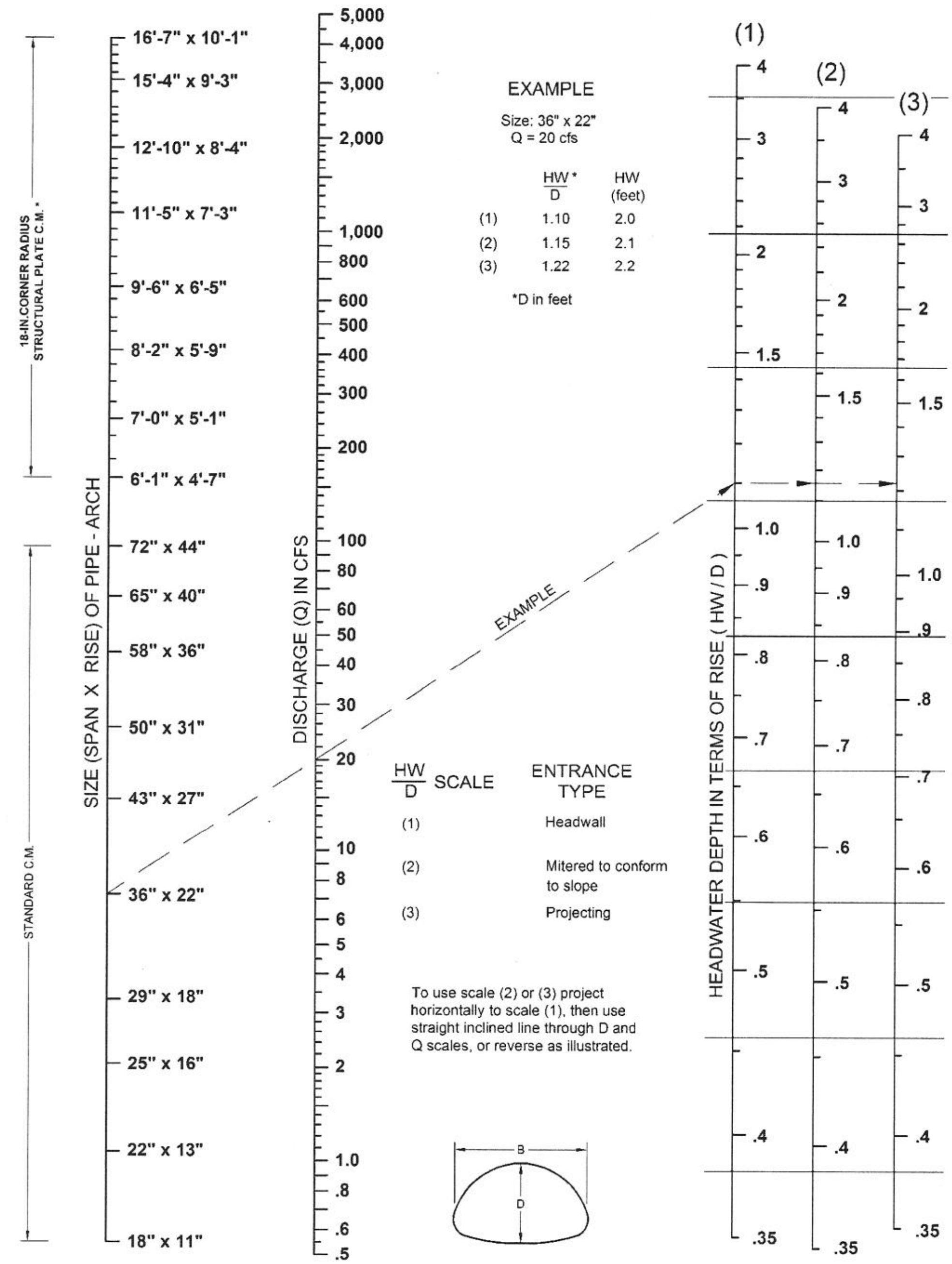
CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS VERTICAL

CHART 33



HEAD FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS HORIZONTAL OR VERTICAL
FLOWING FULL
n=0.012

BUREAU OF PUBLIC ROADS JAN. 1963



* ADDITIONAL SIZES NOT DIMENSIONED ARE LISTED IN FABRICATOR'S CATALOG

BUREAU OF PUBLIC ROADS JAN. 1963

HEADWATER DEPTH FOR C. M. PIPE - ARCH CULVERTS WITH INLET CONTROL

CHART 35

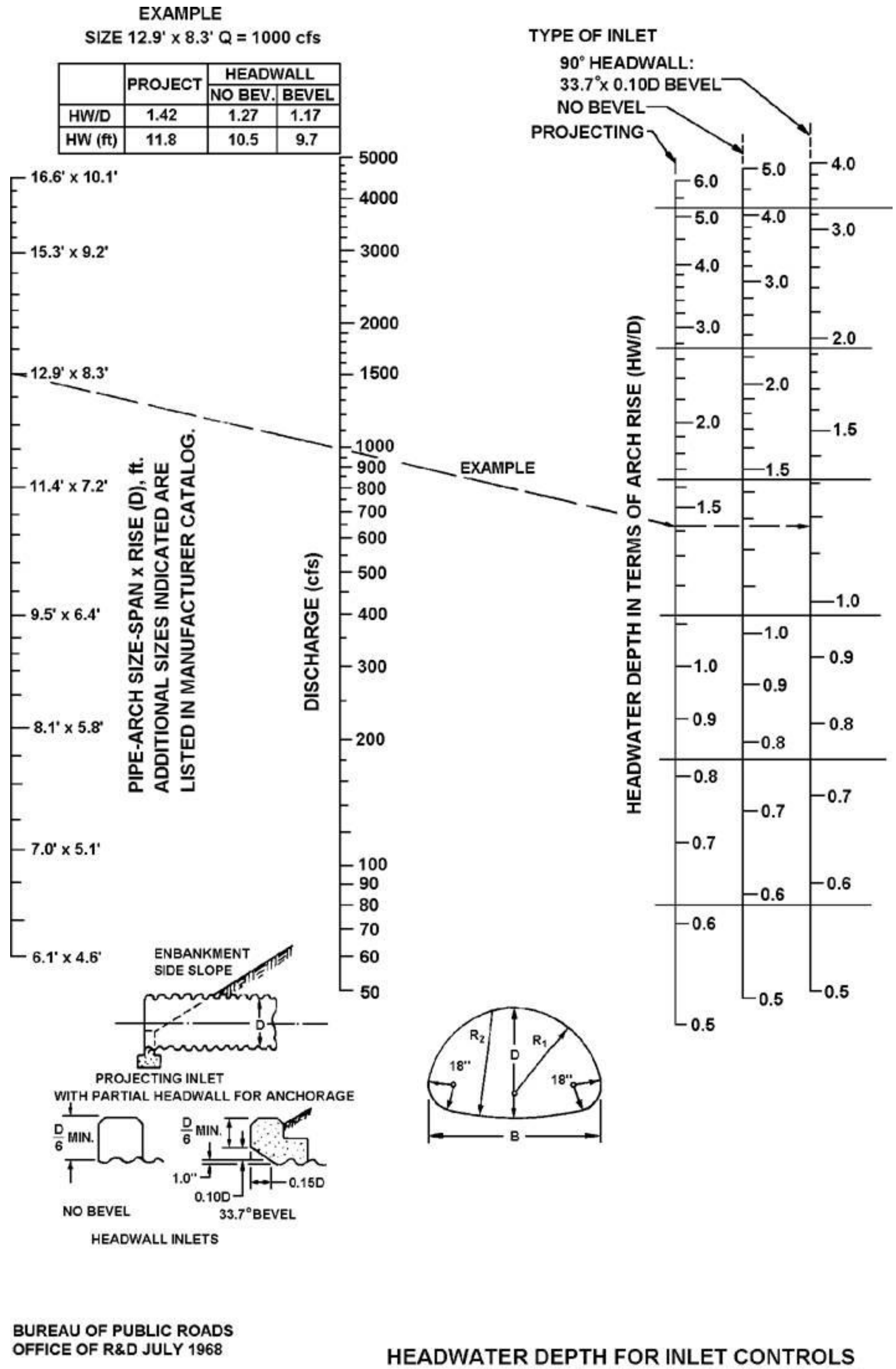
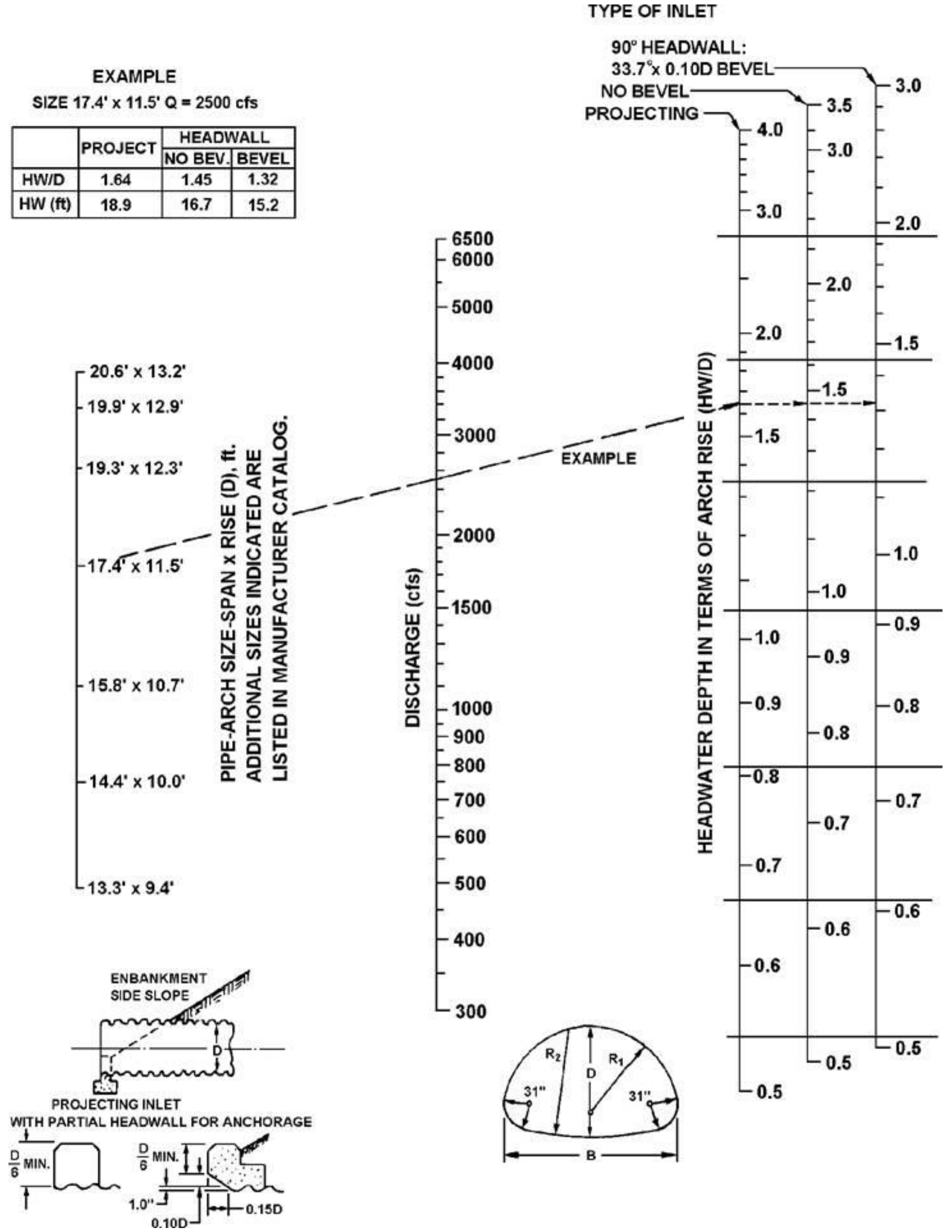

EXAMPLE
SIZE 12.9' x 8.3' Q = 1000 cfs
PROJECT
HEADWALL
NO BEV.
BEVEL
HW/D
1.42
1.27
1.17
HW (ft)
11.8
10.5
9.7
TYPE OF INLET
90° HEADWALL:
33.7° x 0.10D BEVEL
NO BEVEL
PROJECTING
16.6' x 10.1'
15.3' x 9.2'
12.9' x 8.3'
11.4' x 7.2'
9.5' x 6.4'
8.1' x 5.8'
7.0' x 5.1'
6.1' x 4.6'
PIPE-ARCH SIZE-SPAN x RISE (D), ft.
ADDITIONAL SIZES INDICATED ARE
LISTED IN MANUFACTURER CATALOG.
DISCHARGE (cfs)
EXAMPLE
HEADWATER DEPTH IN TERMS OF ARCH RISE (HW/D)
ENBANKMENT
SIDE SLOPE
PROJECTING INLET
WITH PARTIAL HEADWALL FOR ANCHORAGE
D/6 MIN.
1.0"
0.10D
0.15D
NO BEVEL
33.7° BEVEL
HEADWALL INLETS
18"
B
BUREAU OF PUBLIC ROADS
OFFICE OF R&D JULY 1968
HEADWATER DEPTH FOR INLET CONTROLS
STRUCTURAL PLATE PIPE-ARCH CULVERTS
18 in. RADIUS CORNER PLATE
PROJECTING OR HEADWALL INLET
HEADWALL WITH OR WITHOUT EDGE BEVEL

CHART 36

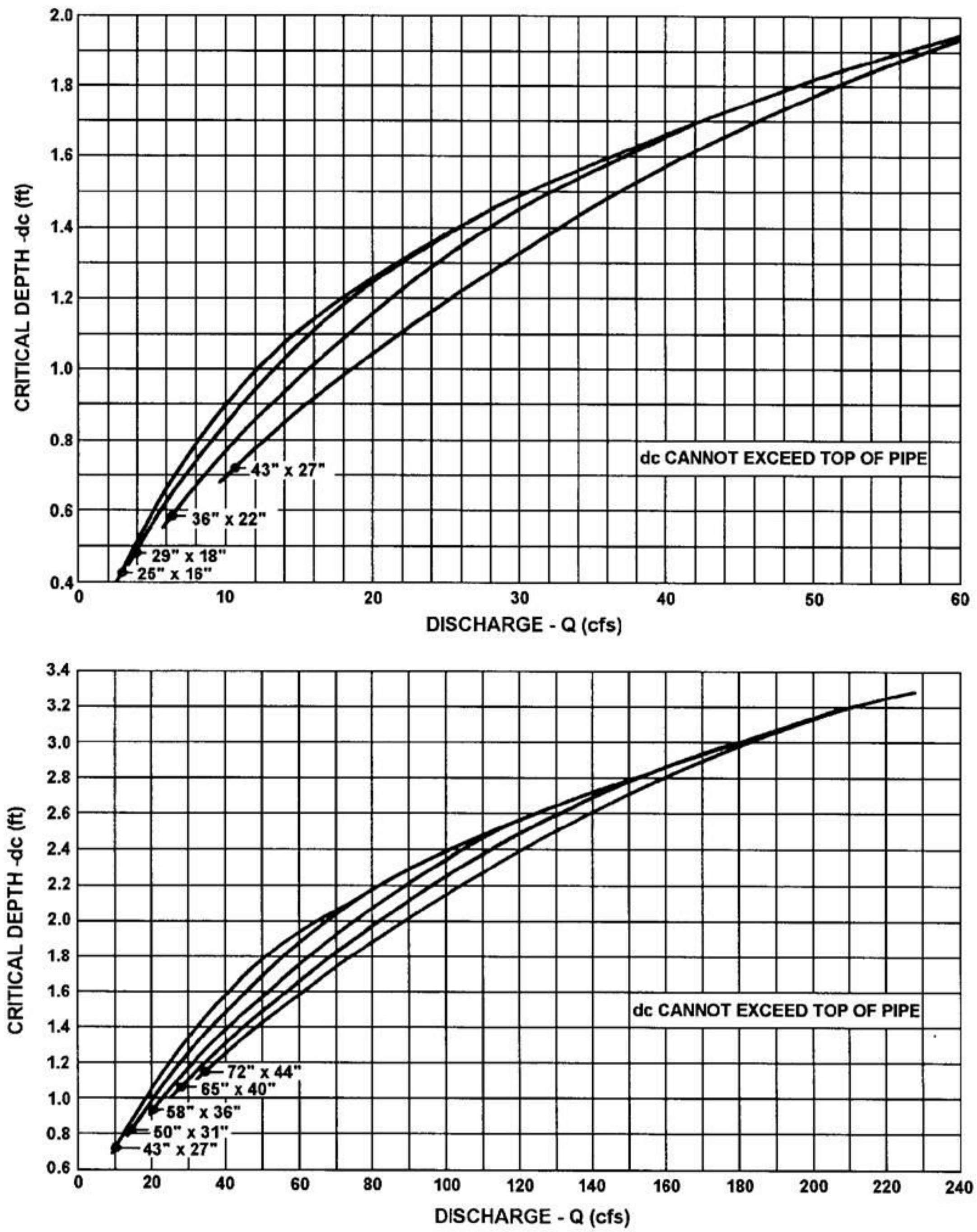


	PROJECT	HEADWALL	
		NO BEV.	BEVEL
HW/D	1.64	1.45	1.32
HW (ft)	18.9	16.7	15.2

BUREAU OF PUBLIC ROADS
OFFICE OF R&D JULY 1966

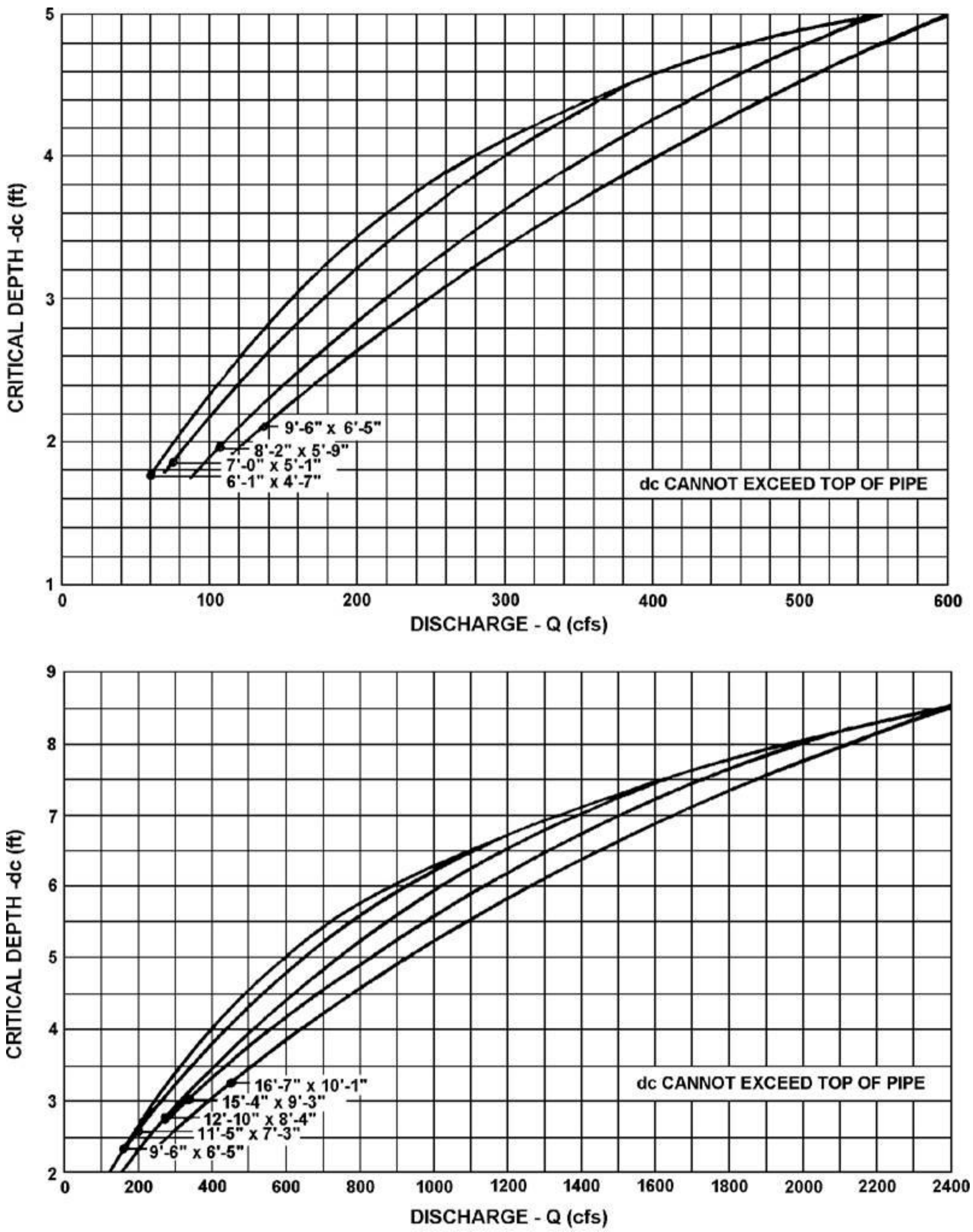
HEADWATER DEPTH FOR INLET CONTROL
STRUCTURAL PLATE PIPE-ARCH CULVERTS
31 in. RADIUS CORNER PLATE
PROJECTING OR HEADWALL INLET
HEADWALL WITH OR WITHOUT EDGE BEVEL

CHART 37



BUREAU OF PUBLIC ROADS
JAN. 1964

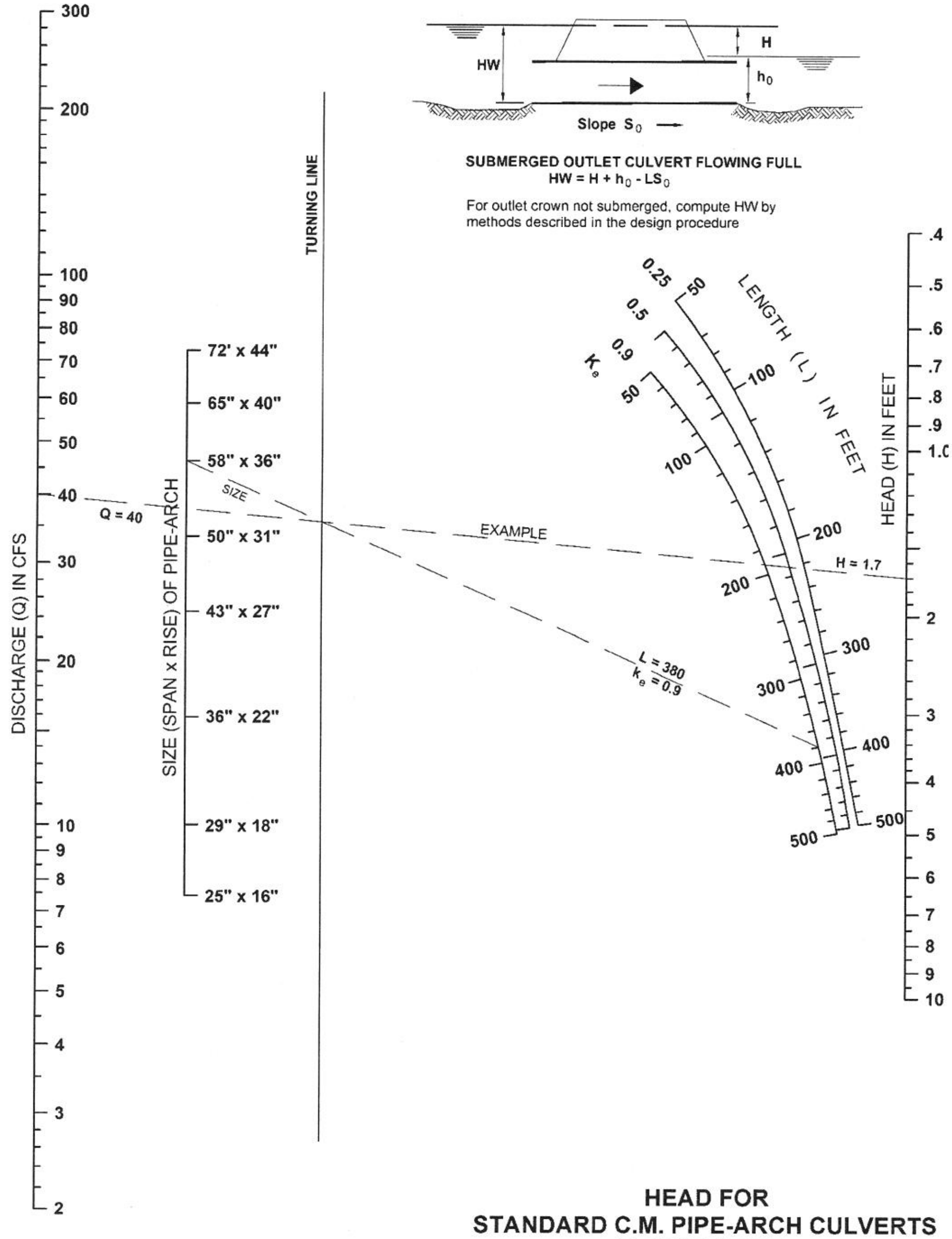
CRITICAL DEPTH
STANDARD C.M. PIPE ARCH



BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
STRUCTURAL PLATE
C.M. PIPE ARCH
18 in. CORNER RADIUS

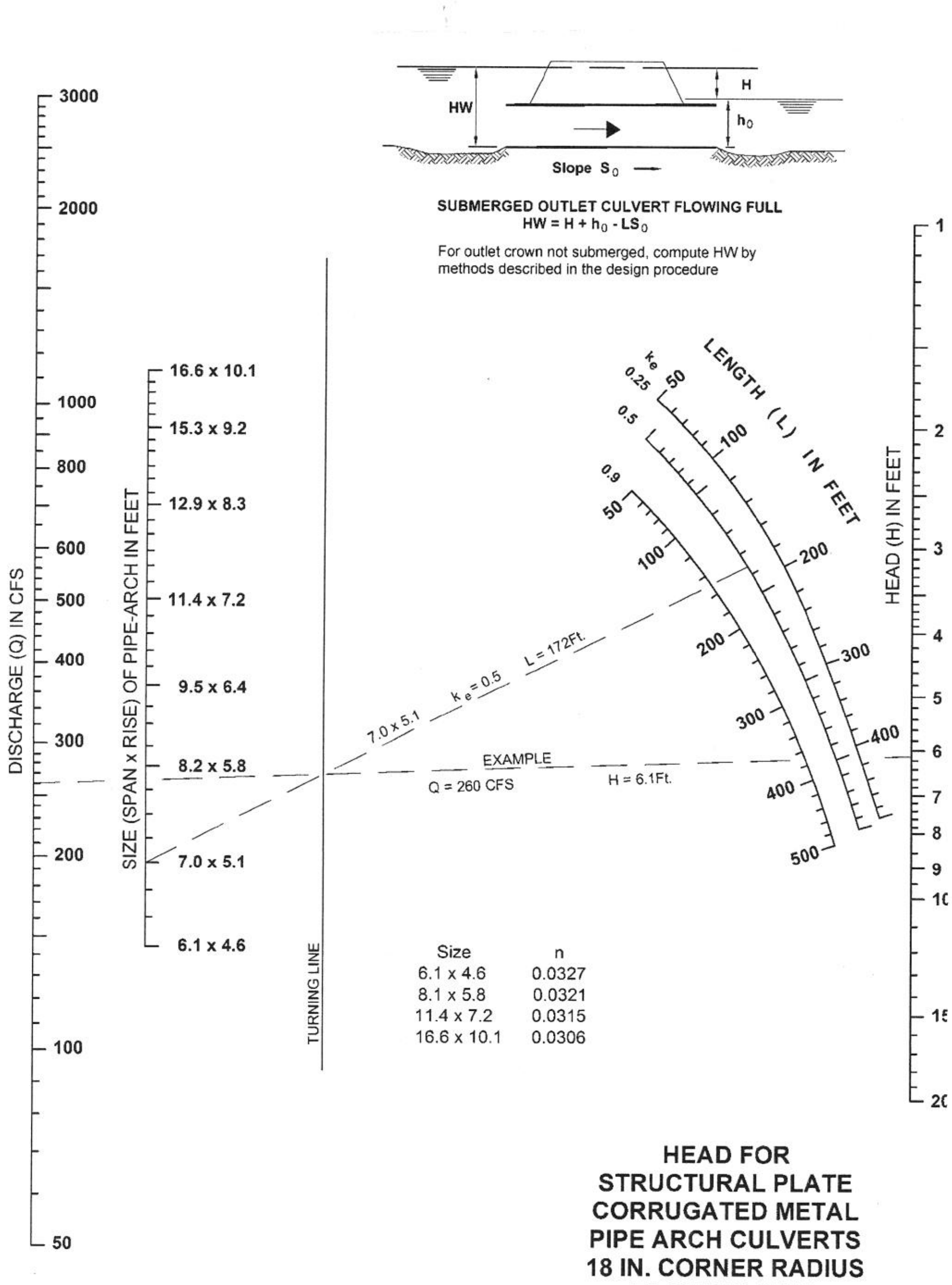
CHART 39



HEAD FOR
STANDARD C.M. PIPE-ARCH CULVERTS
FLOWING FULL
n=0.024

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 40

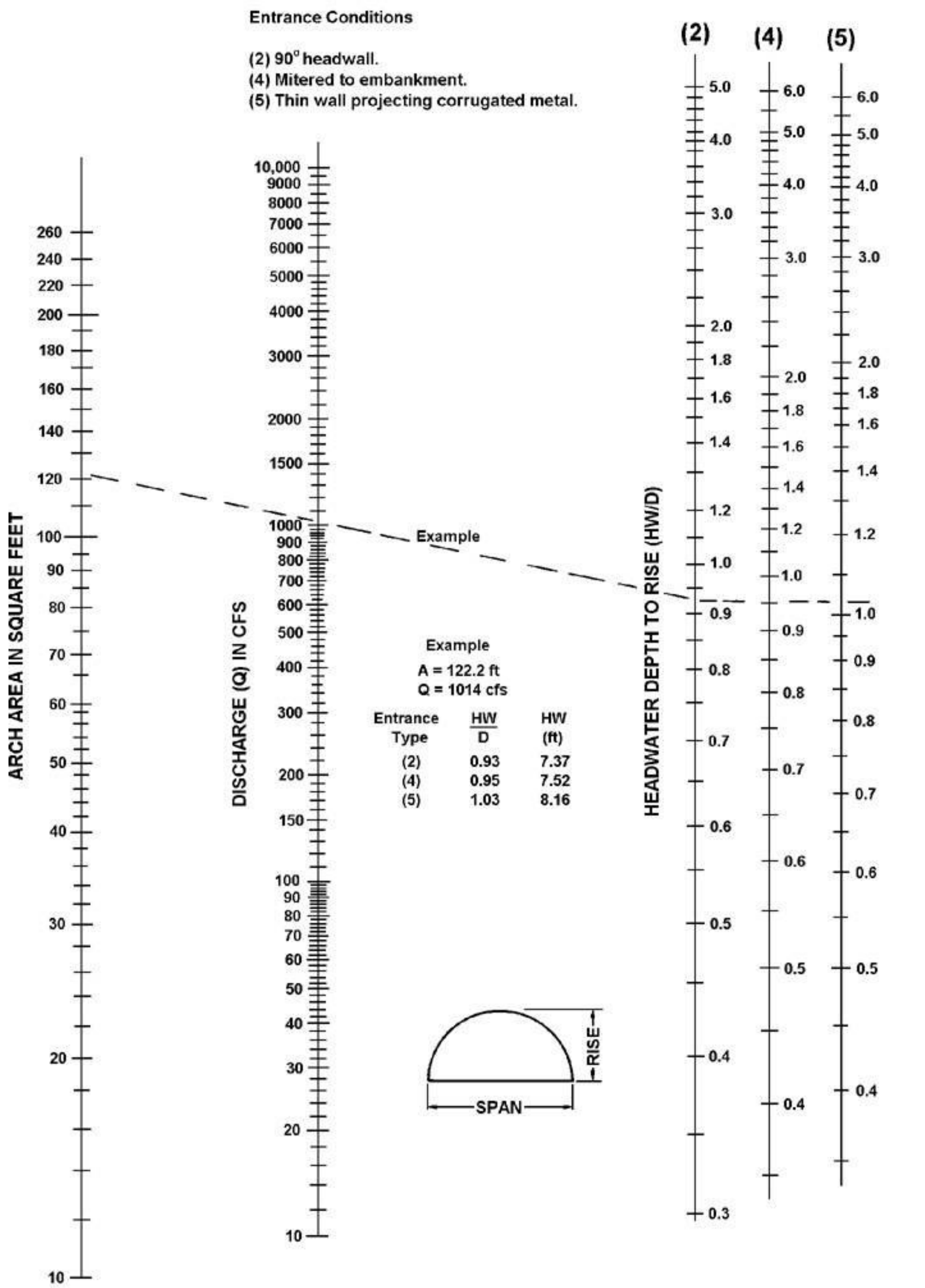


Size	n
6.1 x 4.6	0.0327
8.1 x 5.8	0.0321
11.4 x 7.2	0.0315
16.6 x 10.1	0.0306

HEAD FOR STRUCTURAL PLATE CORRUGATED METAL PIPE ARCH CULVERTS 18 IN. CORNER RADIUS FLOWING FULL n = 0.0327 TO 0.0306

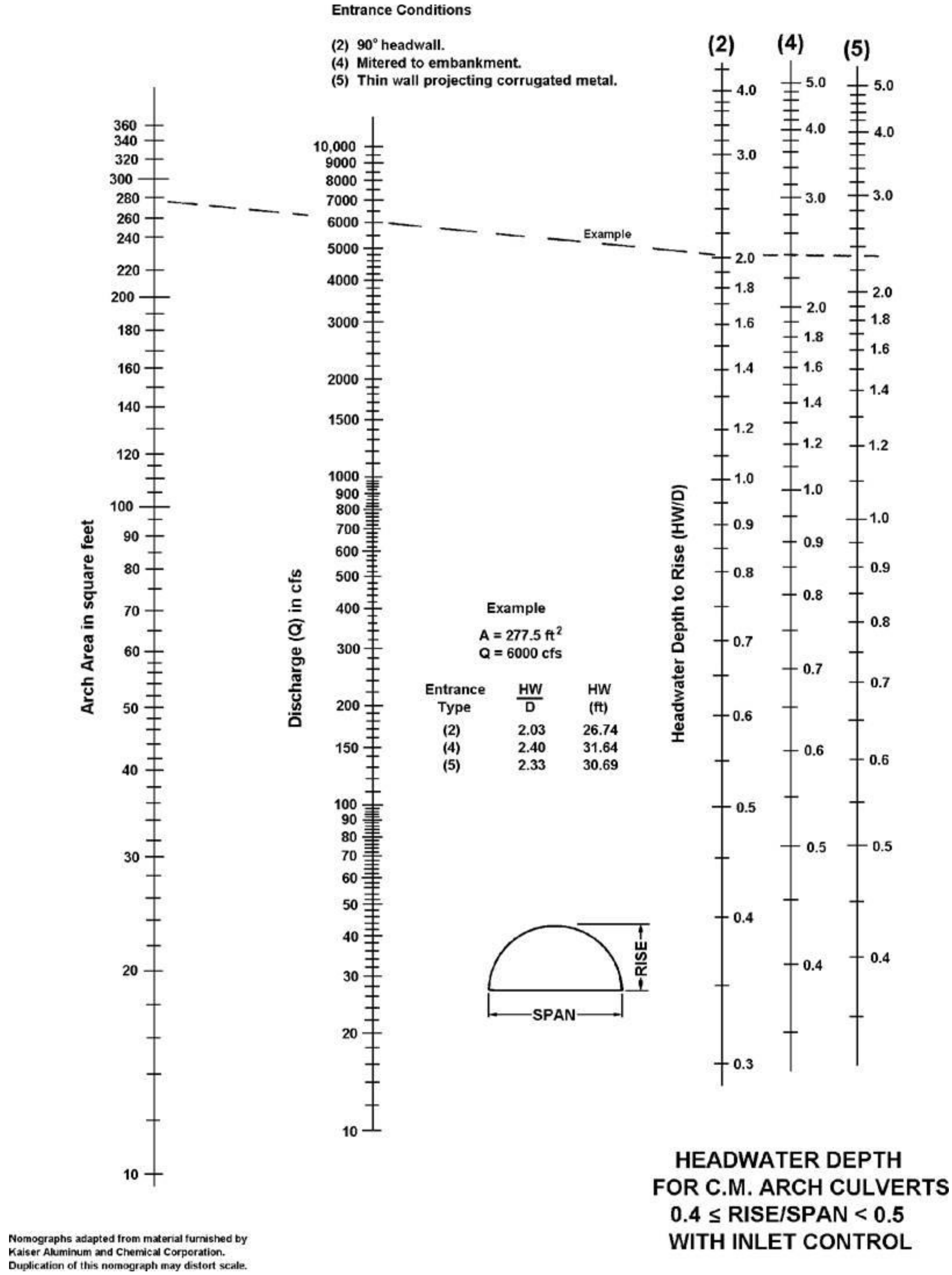
BUREAU OF PUBLIC ROADS JAN. 1963

CHART 41



HEADWATER DEPTH
FOR C.M. ARCH CULVERTS
0.3 ≤ RISE/SPAN < 0.4
WITH INLET CONTROL

CHART 42



Entrance Conditions
(2) 90° headwall.
(4) Mitered to embankment.
(5) Thin wall projecting corrugated metal.
Arch Area in square feet
Discharge (Q) in cfs
Headwater Depth to Rise (HW/D)
Example
Example
A = 277.5 ft²
Q = 6000 cfs
Entrance Type | HW/D | HW (ft)
(2) 2.03 26.74
(4) 2.40 31.64
(5) 2.33 30.69
RISE
SPAN
HEADWATER DEPTH
FOR C.M. ARCH CULVERTS
0.4 ≤ RISE/SPAN < 0.5
WITH INLET CONTROL
Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

CHART 43

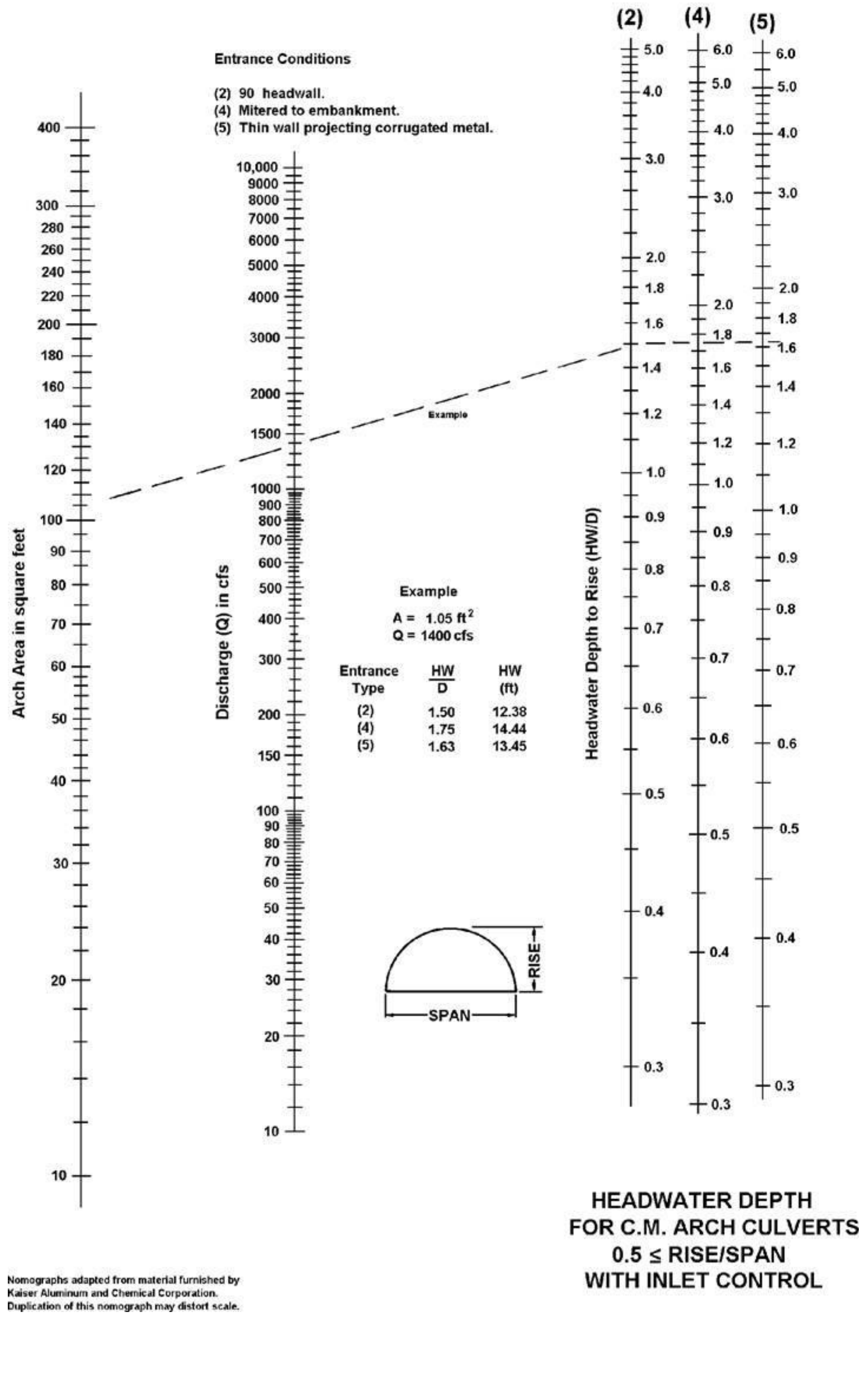
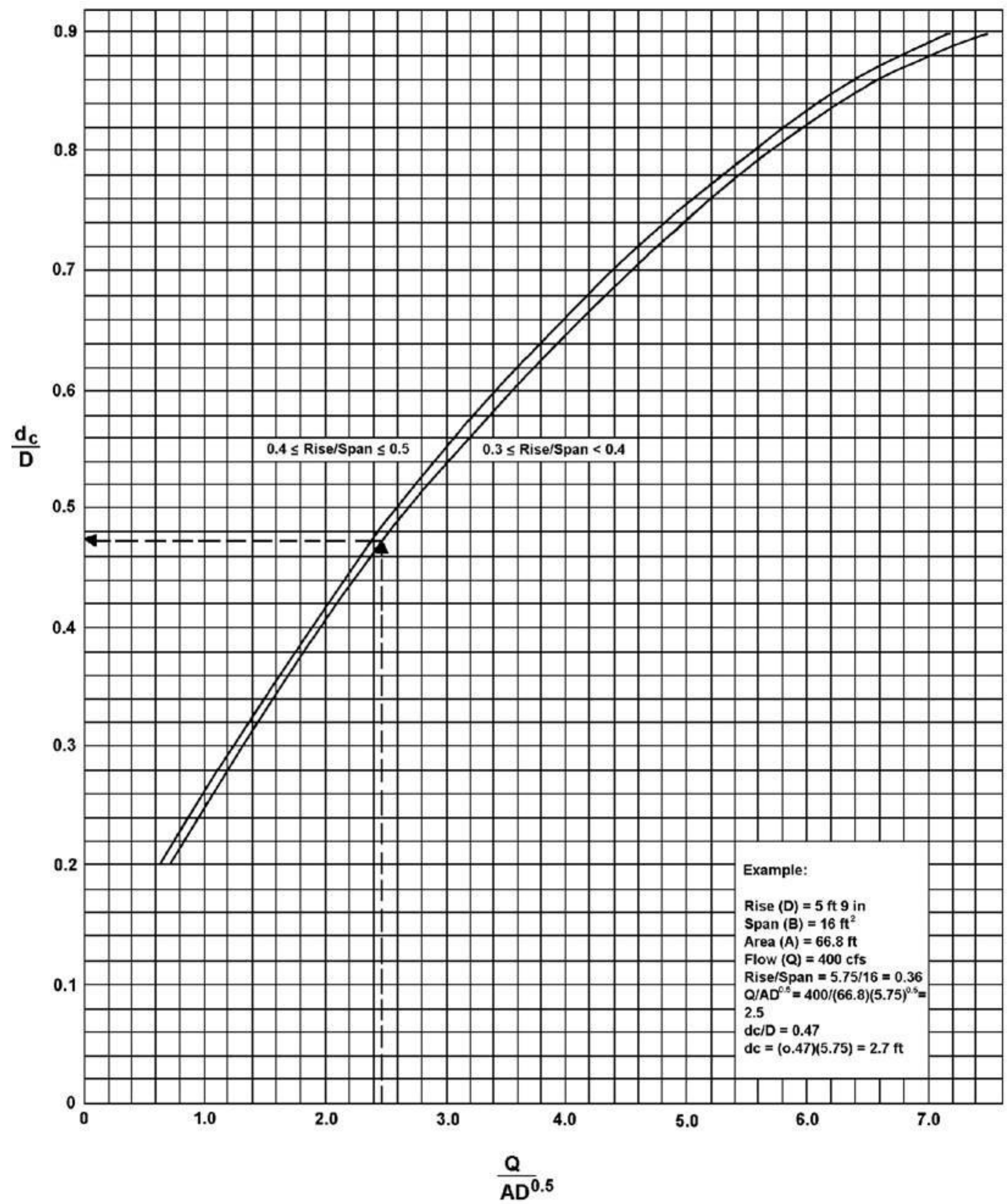
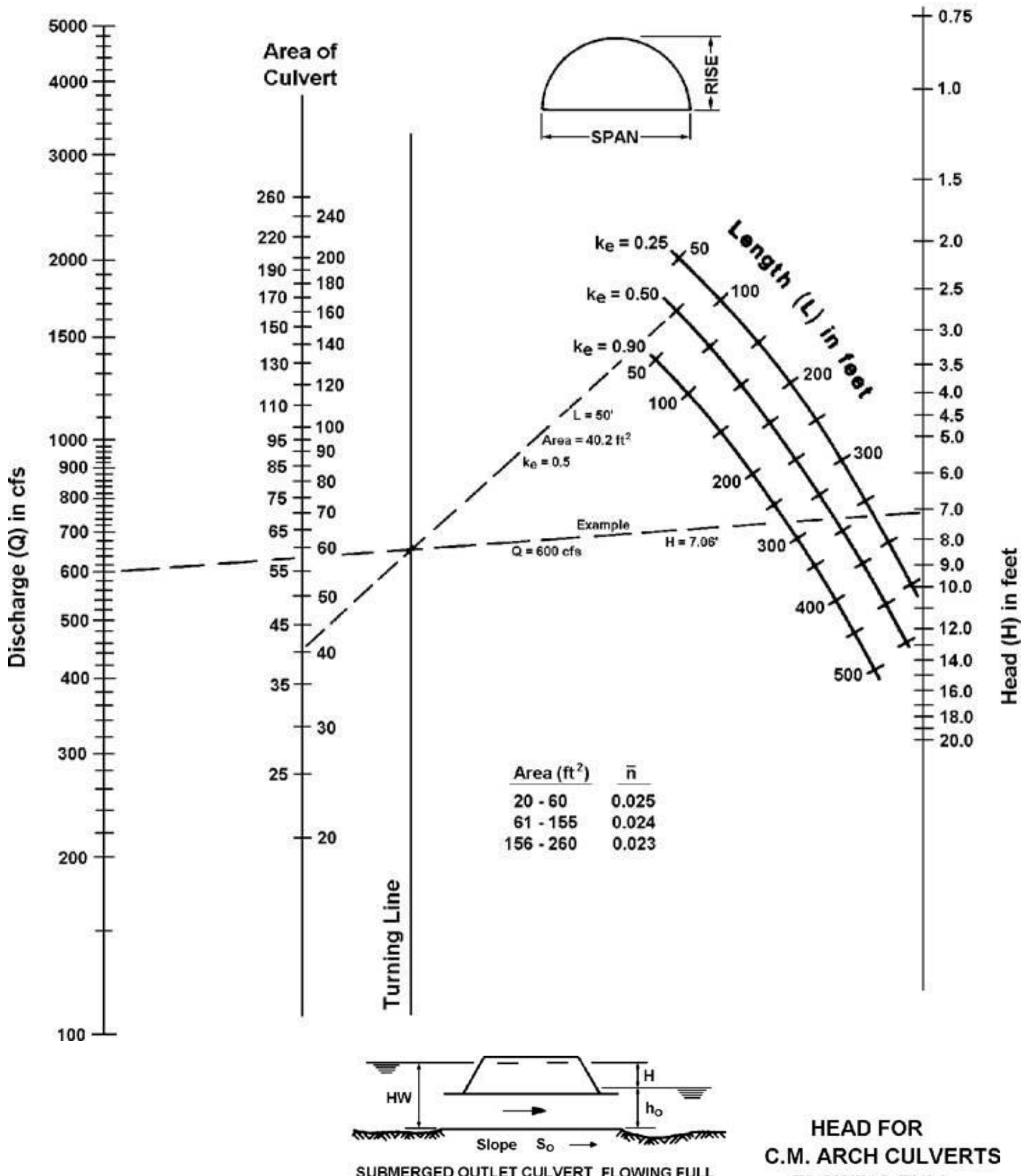

Entrance Conditions
(2) 90 headwall.
(4) Mitered to embankment.
(5) Thin wall projecting corrugated metal.
Arch Area in square feet
Discharge (Q) in cfs
Headwater Depth to Rise (HW/D)
(2)
(4)
(5)
Example
Example
A = 1.05 ft²
Q = 1400 cfs
Entrance Type
HW/D
HW (ft)
(2) 1.50 12.38
(4) 1.75 14.44
(5) 1.63 13.45
RISE
SPAN
HEADWATER DEPTH
FOR C.M. ARCH CULVERTS
0.5 ≤ RISE/SPAN
WITH INLET CONTROL
Nomographs adapted from material furnished by
Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

CHART 44



DIMENSIONLESS CRITICAL DEPTH CHART
FOR C.M. ARCH CULVERTS

CHART 45

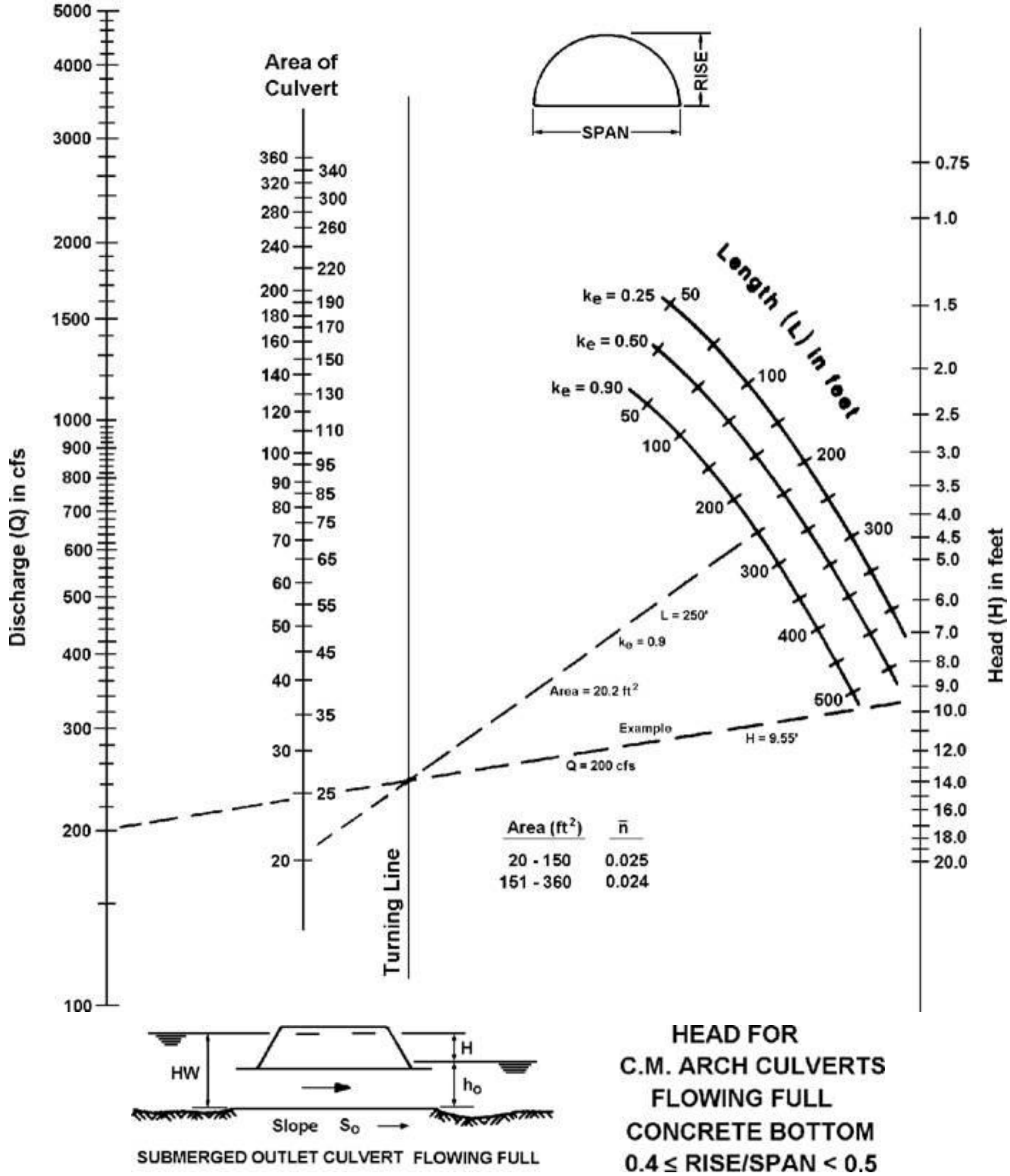


Area (ft²)	$\bar{n}$
20 - 60	0.025
61 - 155	0.024
156 - 260	0.023

HEAD FOR C.M. ARCH CULVERTS FLOWING FULL CONCRETE BOTTOM $0.3 \leq$ RISE/SPAN < 0.4

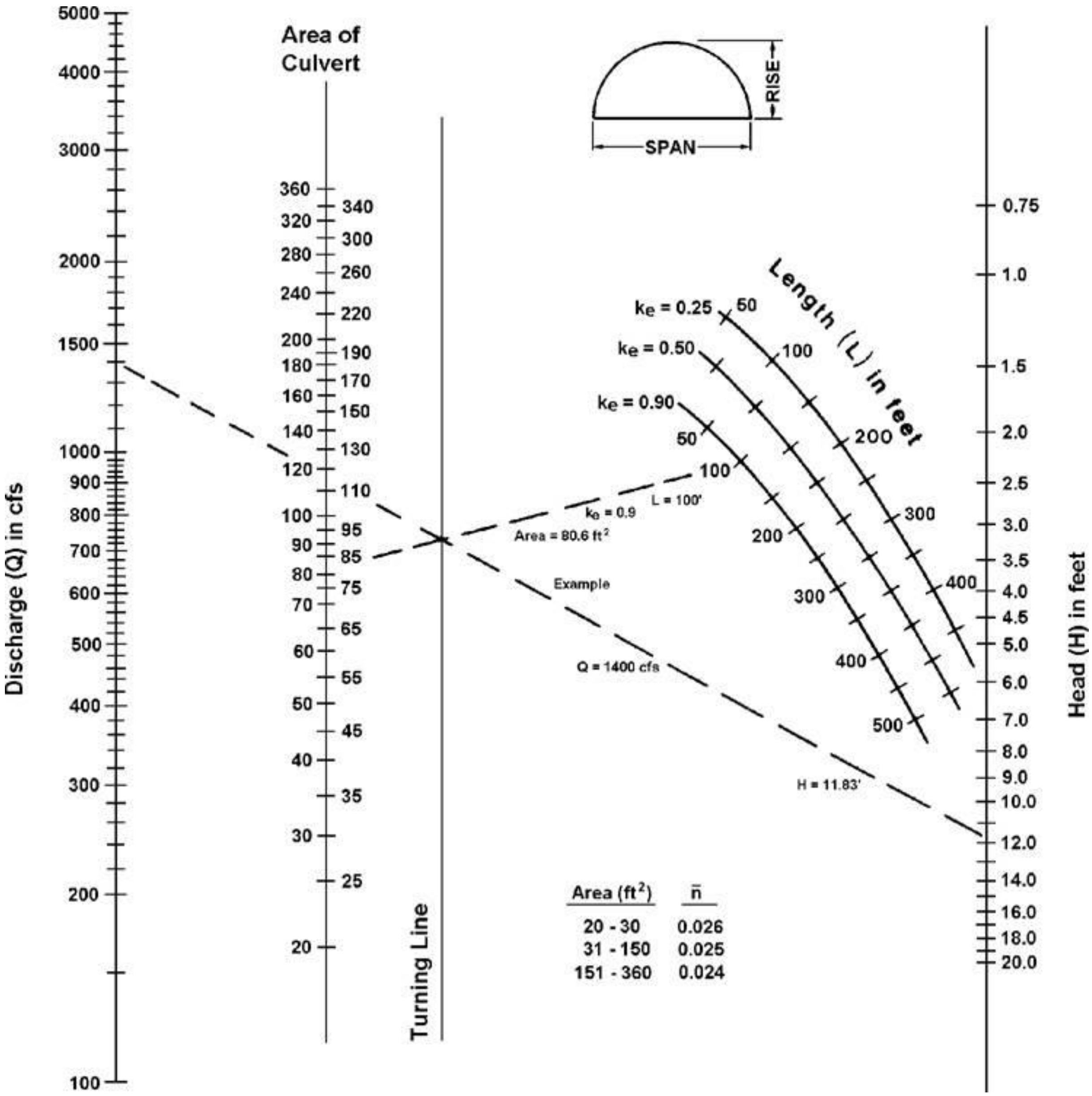
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 46

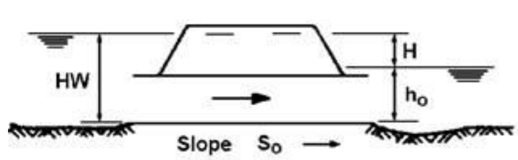


HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
CONCRETE BOTTOM
0.4 ≤ RISE/SPAN < 0.5

CHART 47

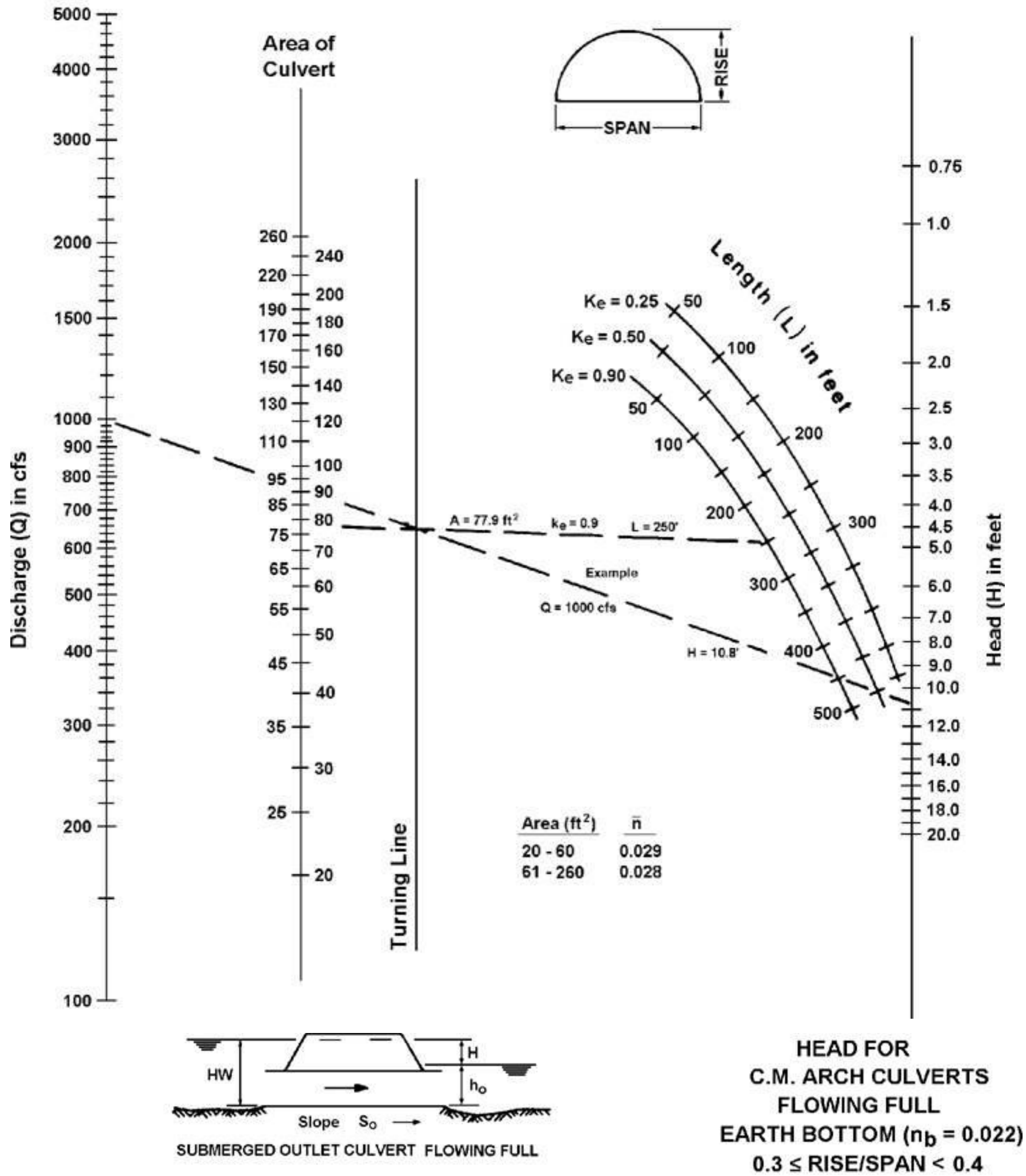


HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
CONCRETE BOTTOM
$0.5 \leq$ RISE/SPAN



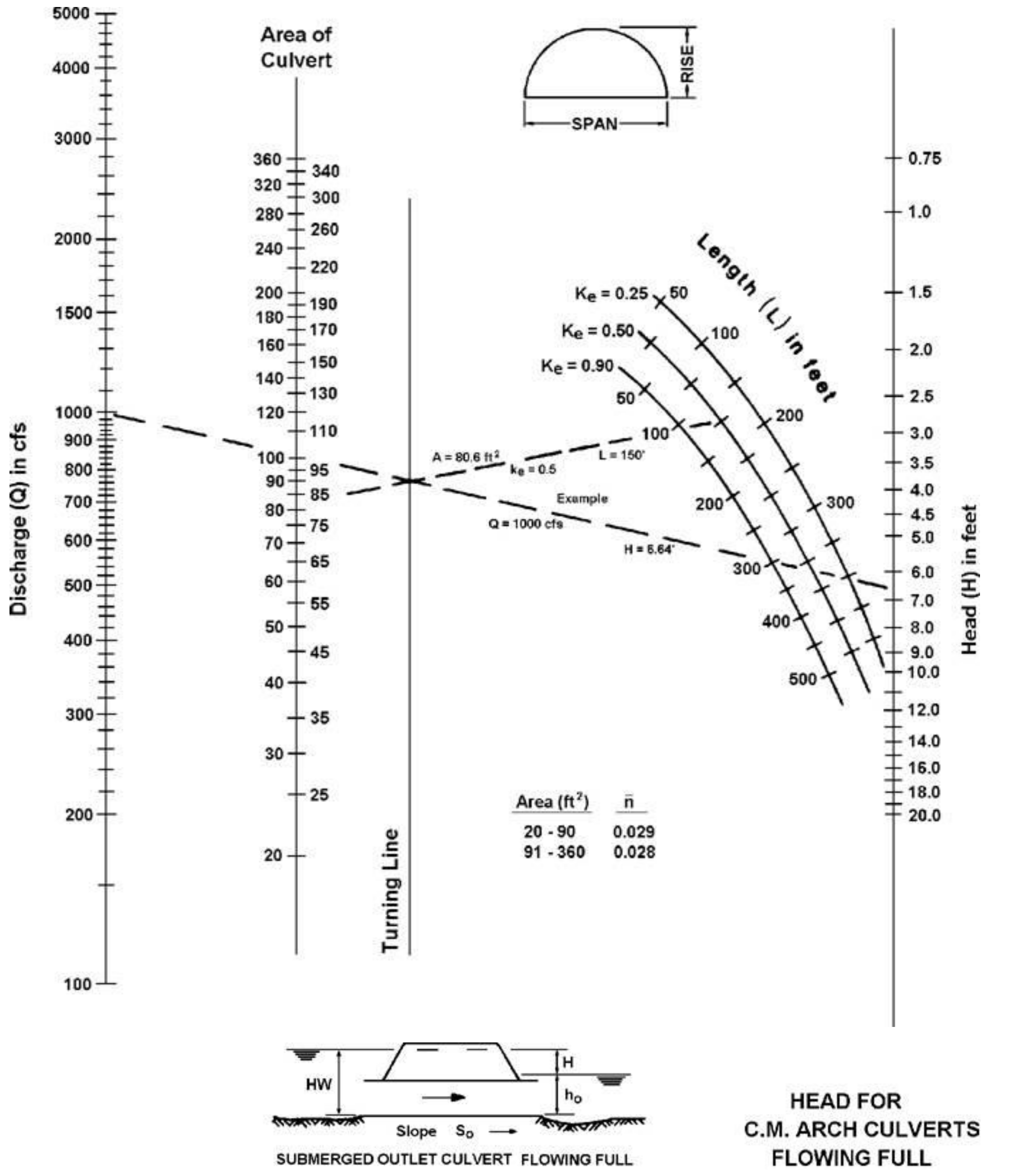
SUBMERGED OUTLET CULVERT FLOWING FULL

CHART 48



Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation.
Duplication of this nomograph may distort scale.

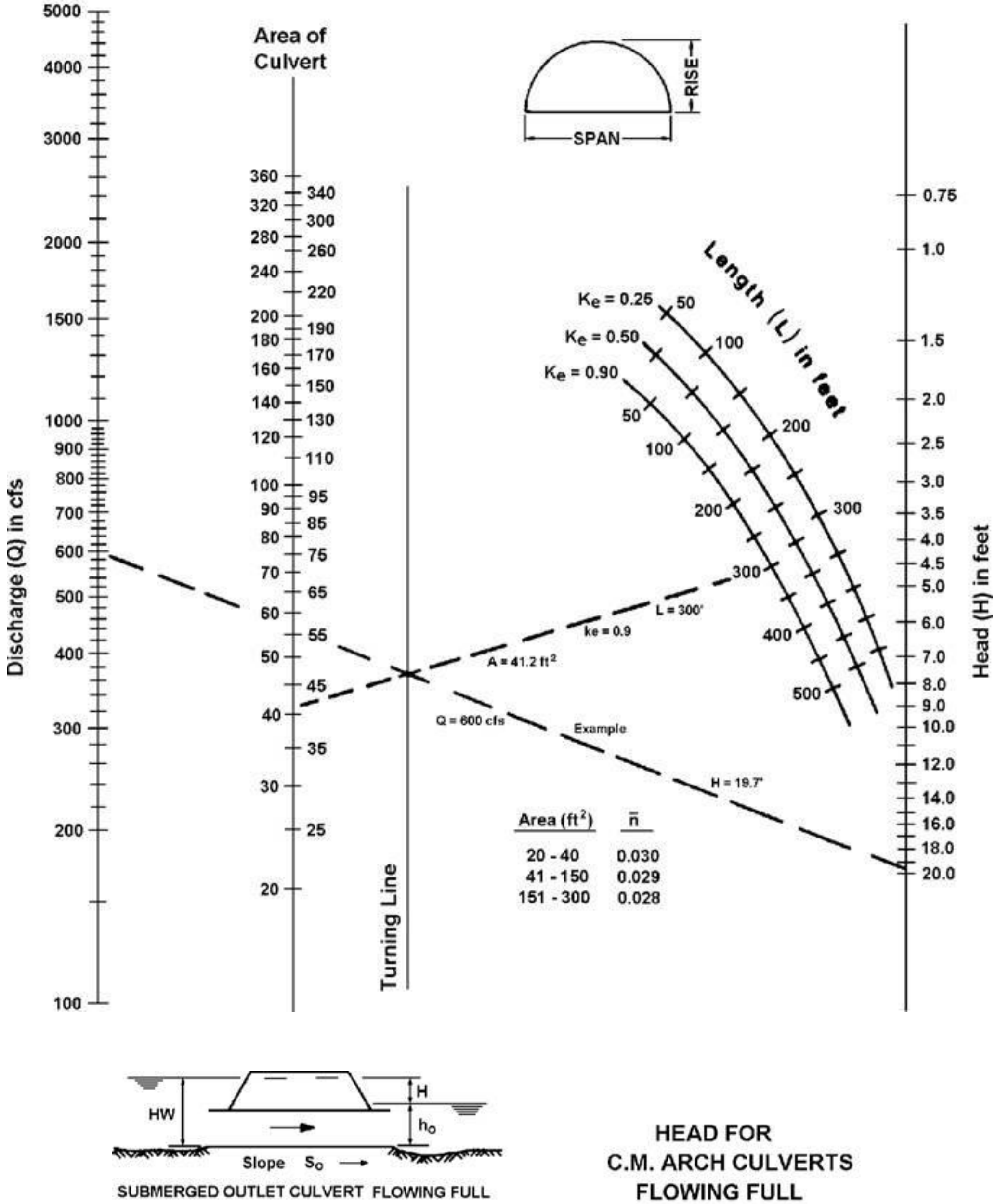
CHART 49



HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
EARTH BOTTOM (n_b = 0.022)
0.4 ≤ RISE/SPAN < 0.5

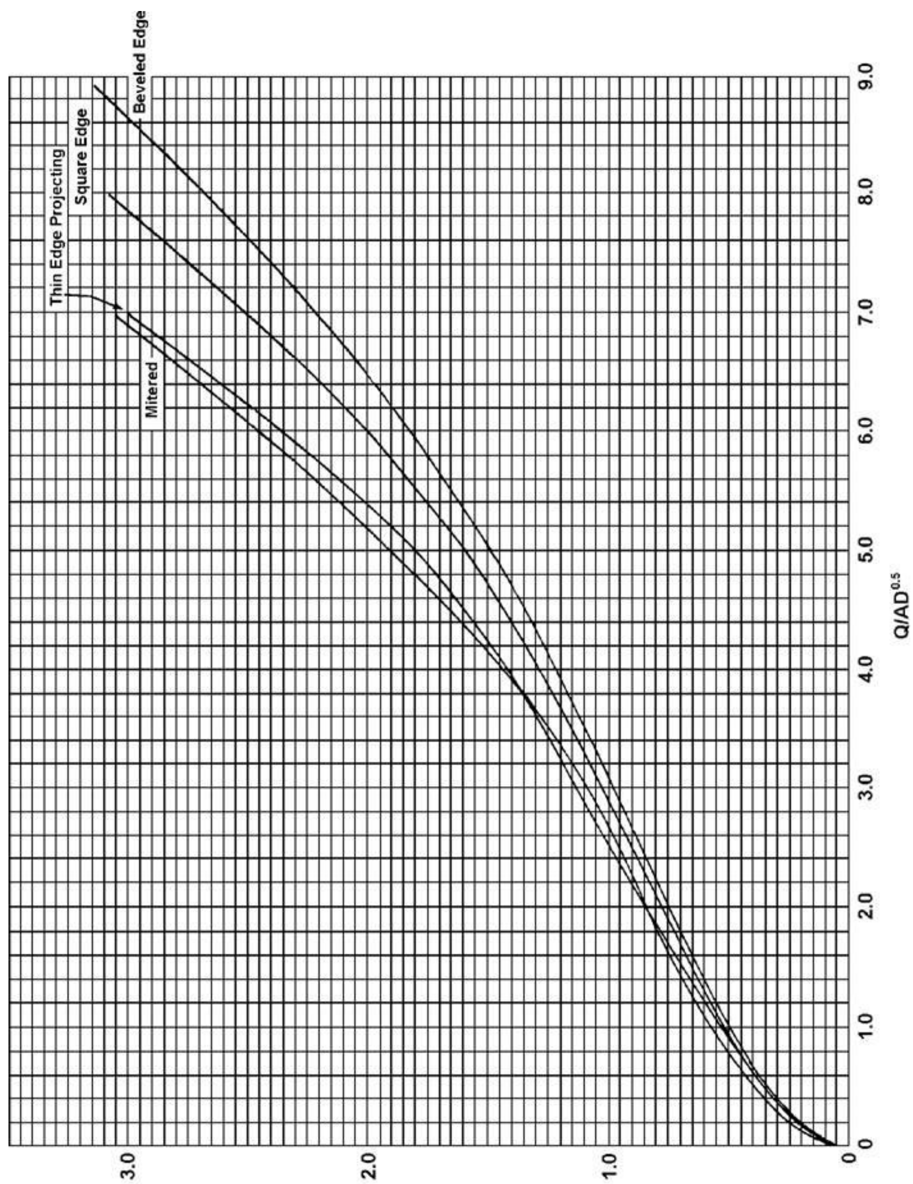
Nomographs adapted from material furnished by Kaiser Aluminum and Chemical Corporation. Duplication of this nomograph may distort scale.

CHART 50



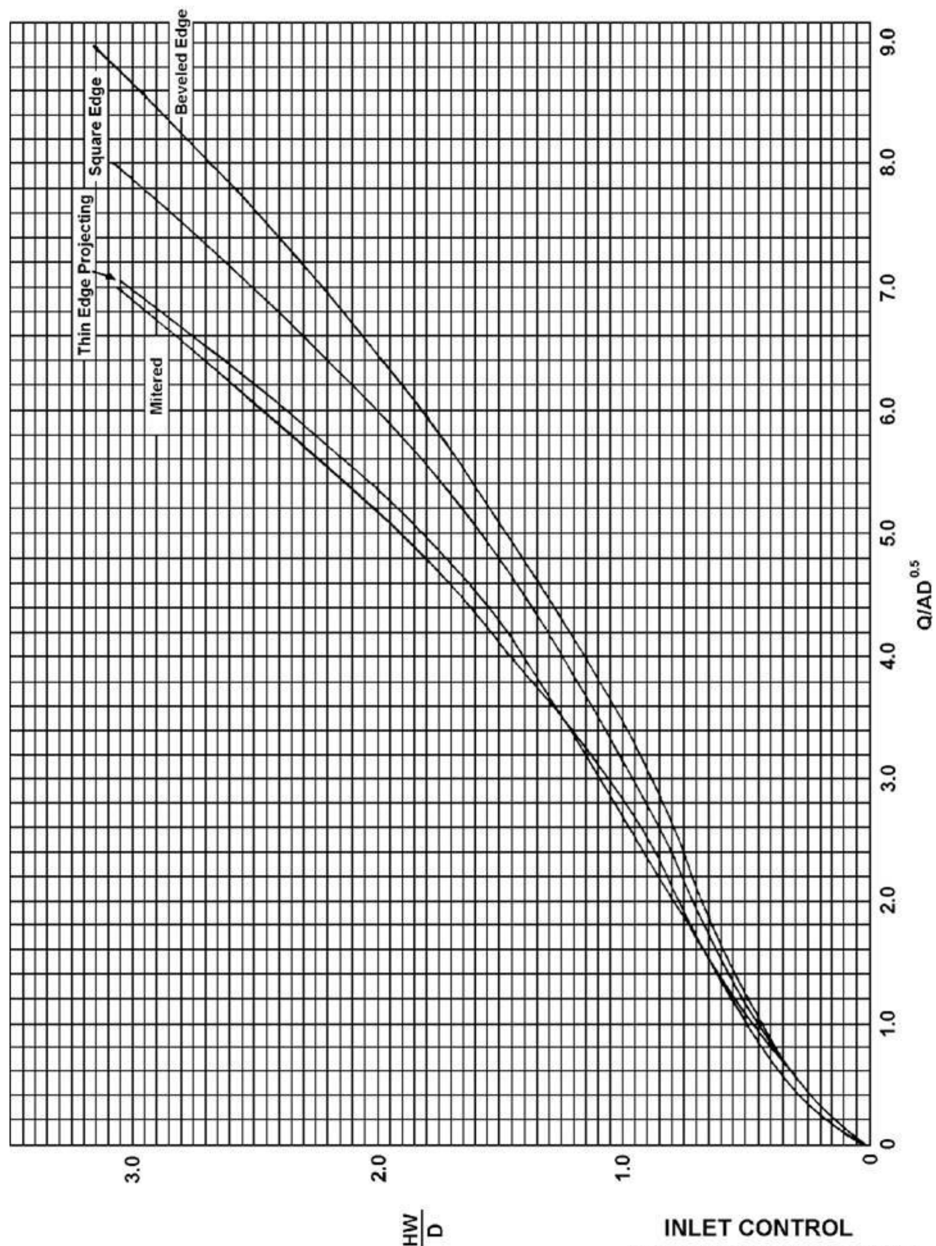
HEAD FOR
C.M. ARCH CULVERTS
FLOWING FULL
EARTH BOTTOM (n_b = 0.022)
0.5 ≤ RISE/SPAN

CHART 51



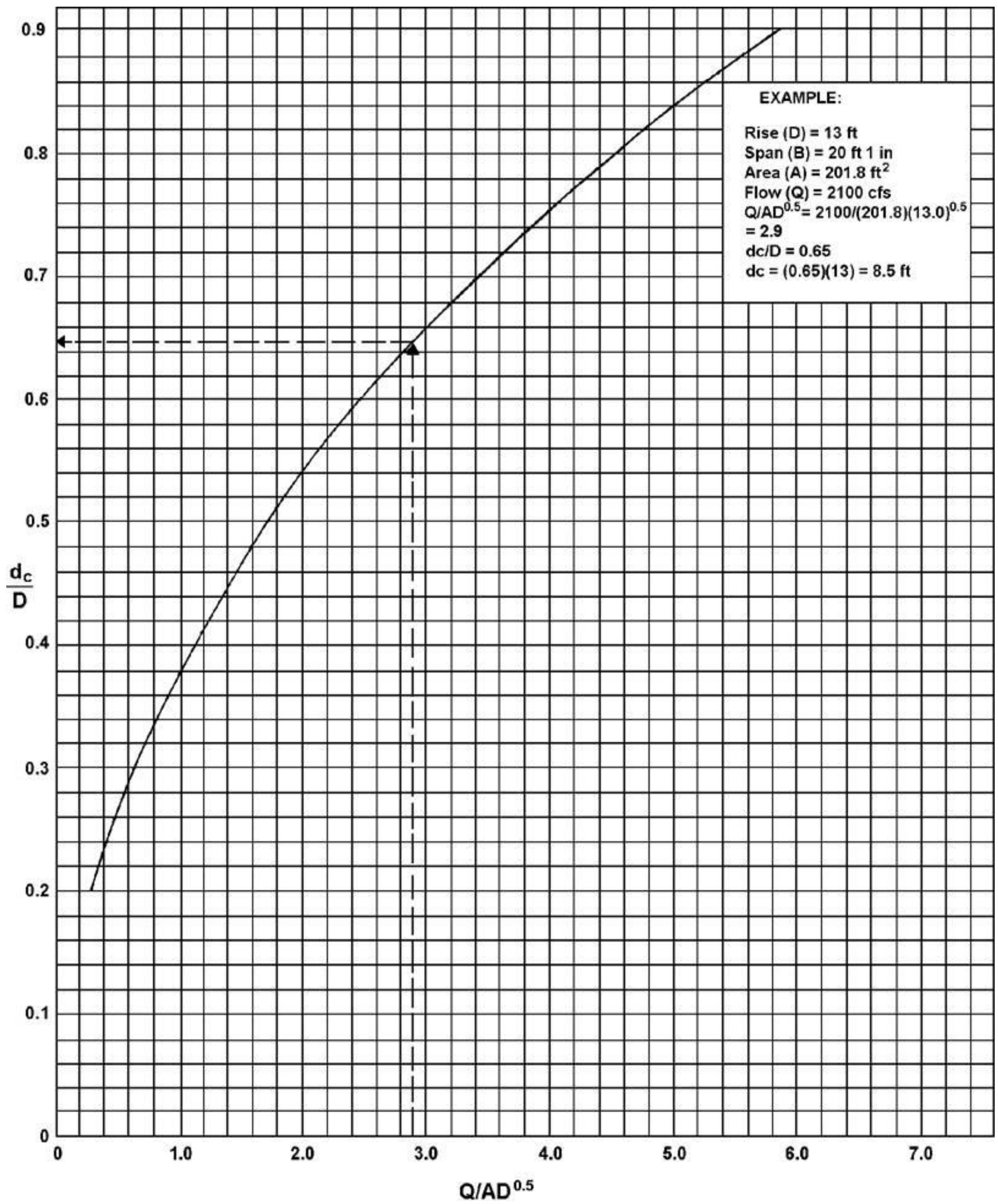
INLET CONTROL
HEADWATER DEPTH FOR
CIRCULAR OR ELLIPTICAL
STRUCTURAL PLATE
C.M. CONDUITS

CHART 52



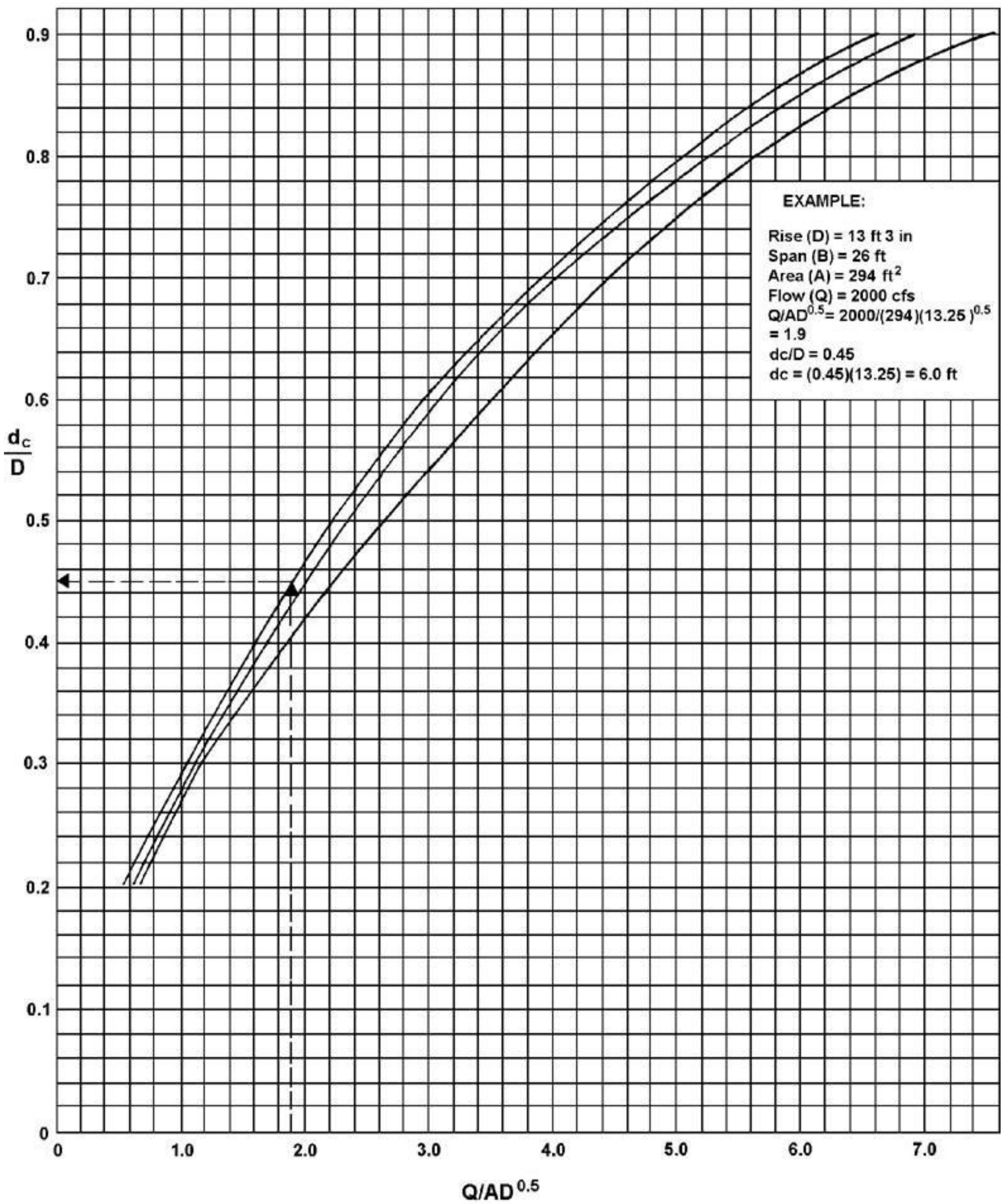
**INLET CONTROL
HEADWATER DEPTH FOR
HIGH AND LOW PROFILE
STRUCTURAL PLATE
C.M. ARCH**

CHART 53



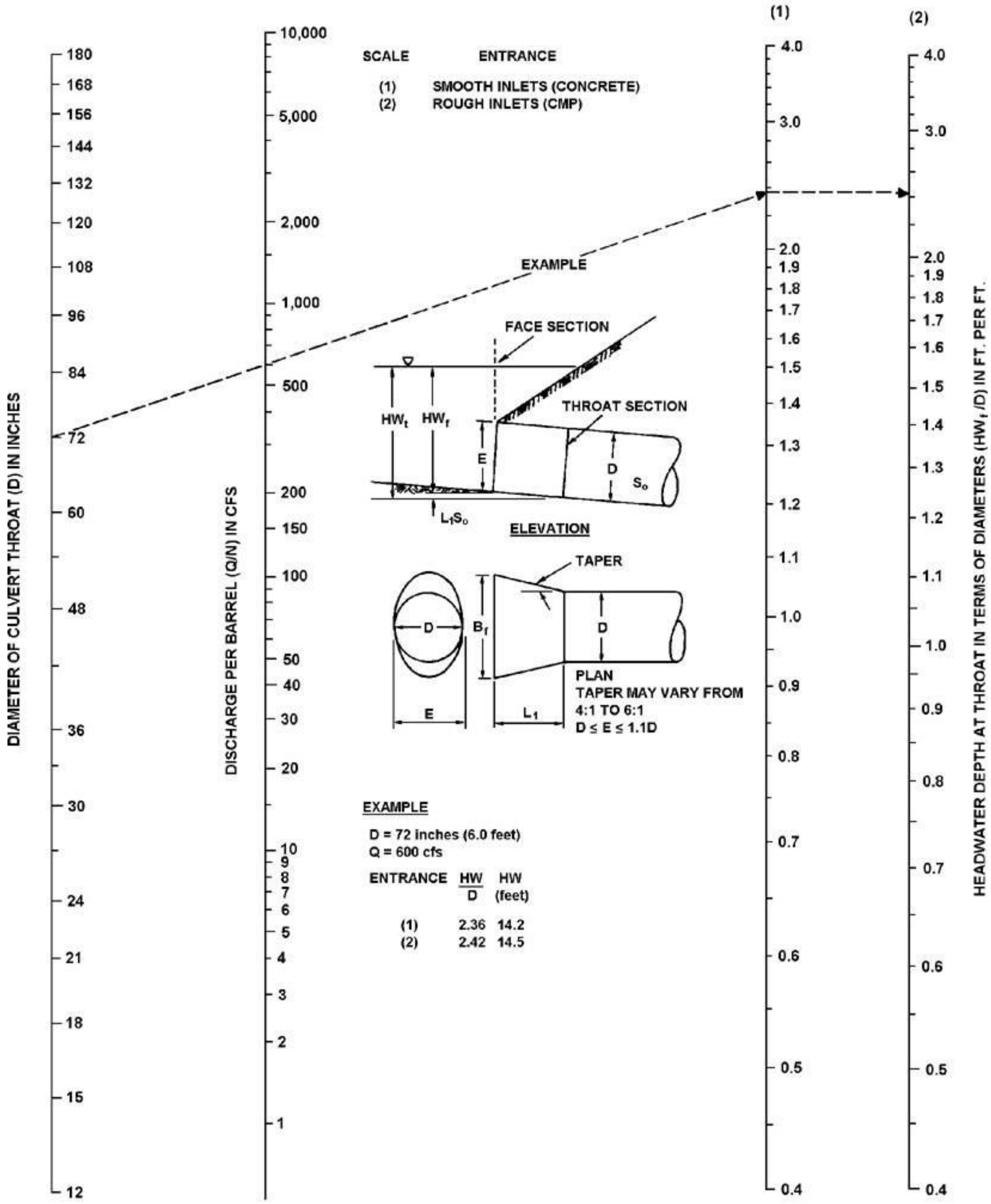
DIMENSIONLESS CRITICAL DEPTH CHART
FOR STRUCTURAL PLATE
ELLIPSE LONG AXIS HORIZONTAL

CHART 54



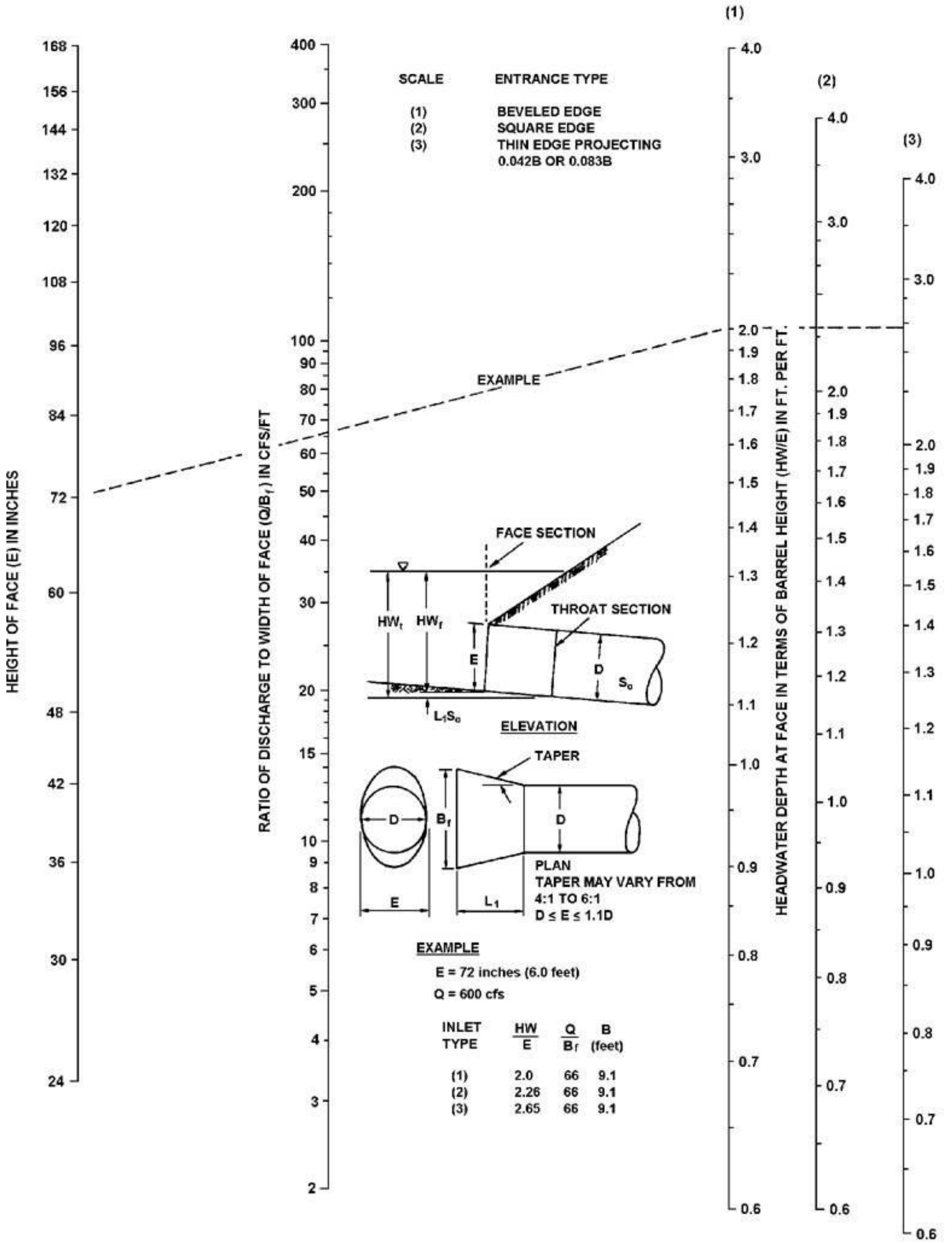
DIMENSIONLESS CRITICAL DEPTH CHART
FOR STRUCTURAL PLATE
LOW- AND HIGH-PROFILE ARCHES

CHART 55



THROAT CONTROL
FOR SIDE-TAPERED INLETS
TO PIPE CULVERT
(CIRCULAR SECTION ONLY)

CHART 56



EXAMPLE

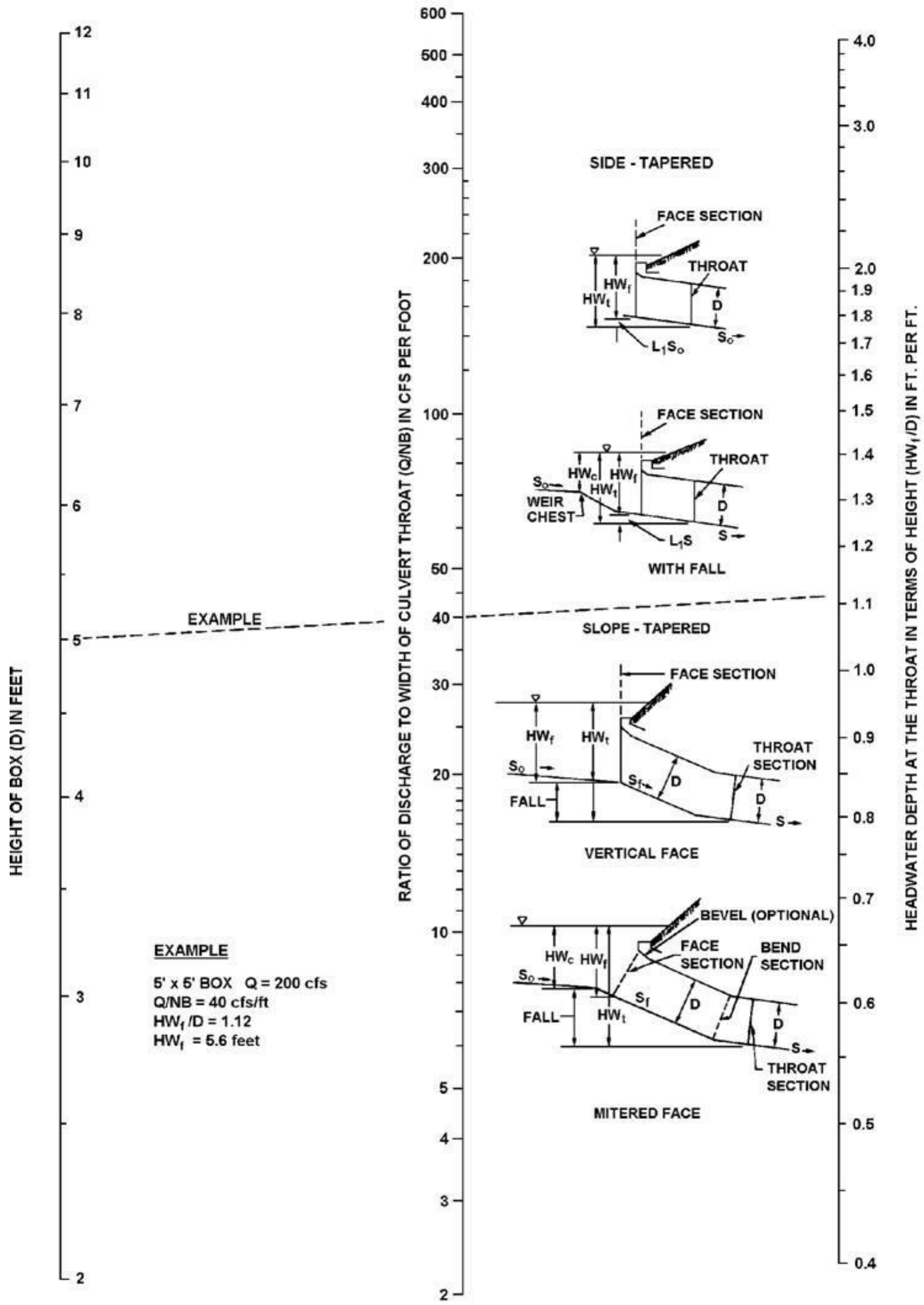
E = 72 inches (6.0 feet)

Q = 600 cfs

INLET TYPE	HW/E	Q/B$_f$	B (feet)
(1)	2.0	66	9.1
(2)	2.26	66	9.1
(3)	2.65	66	9.1

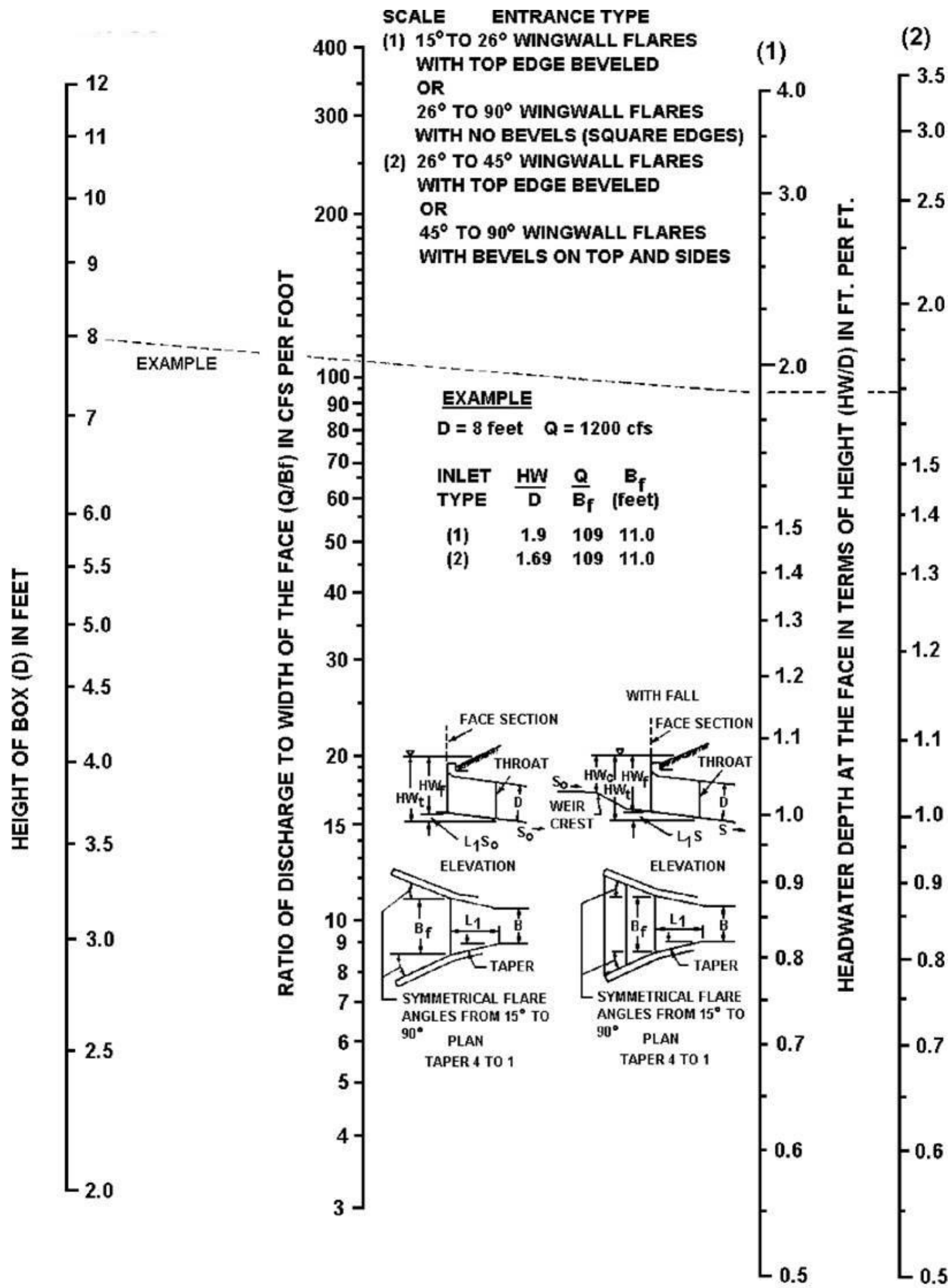
FACE CONTROL FOR SIDE-TAPERED
INLETS TO PIPE CULVERTS
(NON-RECTANGULAR SECTIONS ONLY)

CHART 57



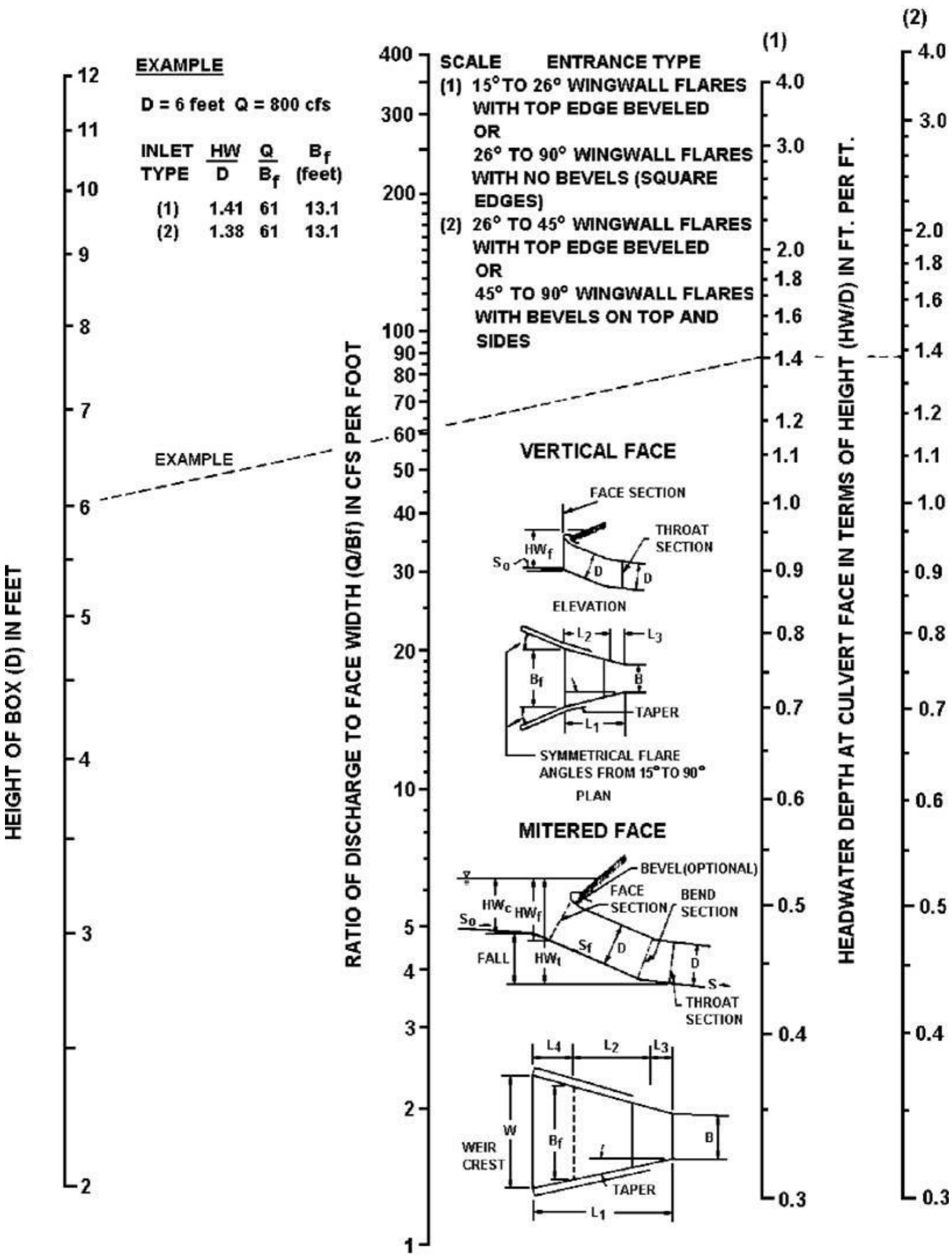
THROAT CONTROL FOR BOX CULVERTS WITH TAPERED INLETS

CHART 58



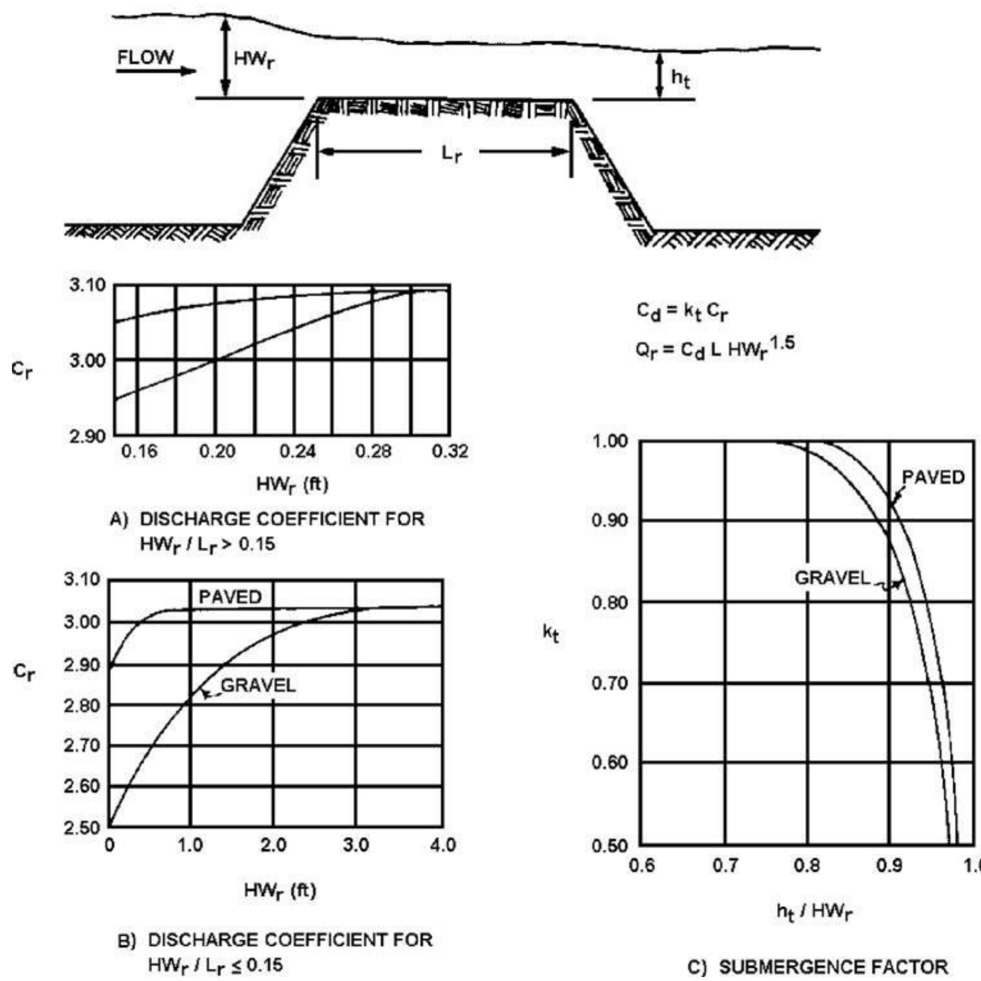
FACE CONTROL FOR BOX CULVERTS WITH SIDE-TAPERED INLETS

CHART 59



FACE CONTROL FOR BOX CULVERTS WITH SLOPE TAPERED INLETS

CHART 60



DIMENSIONLESS COEFFICIENTS

FOR ROADWAY OVERTOPPING